United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park, NC 27711

EPA-450/3-75-077
September 1975

Air

EPA

SELECTING SITES FOR CARBON MONOXIDE MONITORING

EPA-450/3-75-07

SELECTING SITES FOR CARBON MONOXIDE MONITORING

by

F.L. Ludwig and J.H.S. Kealoha

Stanford Research Institute
Menlo Park, California 94025

Contract No. 68-02-1471

EPA Project Officer: Neil J. Berg, Jr.

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Caroolin 27711

September 1975

Publication No. EPA-450/3-75-077

ABSTRACT

This report presents procedures and criteria for selecting appropriate locations for carbon monoxide (CO) monitoring stations. The purposes for which CO concentrations are measured are reviewed and classified according to a system based on special scales of representativeness. Different purposes require measurements representative of areas of differing size. The first step of the site selection process is to decide the purpose of the measurements. Then this primary purpose must be related to the kind of area that should be represented by the measurements. A matrix of purposes and spatial scales is included to assist in this determination.

Procedures are given for selecting locations that will provide CO measurements representative of downtown street canyon areas, along major traffic corridors, urban neighborhoods, and larger interurban regions. Specific recommendations are included for inlet heights, distances from major and minor roadways and placement relative to urban areas. Less detailed discussions of monitoring around indirect sources such as shopping centers and stadia are included. The rationale behind the specific recommendations is given. In general, the objective has been to place the monitor so that it is not disproportionately influenced by any one source within the area to be represented.

Appendices discuss sources of information useful to the site selection process, such as climatological data, land use information, and traffic data. A bibliography is also included. It is classified according to monitoring purposes and scales of representativeness. A computer program designed to identify "worst-case" conditions and the relative contributions of sources at different distances is presented.

CONTENTS

CONTENTS (Continued)

CONTENTS (Concluded)

ILLUSTRATIONS

ILLUSTRATIONS (Concluded)

TABLES

ACKNOWLEDGMENTS

The authors have been greatly assisted by the comments and technical advice of many people, particularly Dr. Wayne Ott and Mr. Neil Berg of the Environmental Protection Agency and Messrs. Eugene Shelar, Hisao Shigeishi, and Ms. Sarita Skidmore of Stanford Research Institute. We are also indebted to Ms. Kathey Mabrey, Mr. Gary Parsons, and Mr. Roger Bass for their contributions to the preparation of this report.

SUMMARY

It does not require an extensive review of the literature to conclude that many measurements of carbon monoxide (CO) concentrations are being made and used for a wide variety of purposes. In fact, it sometimes appears that the number of purposes exceeds the number of stations. It is very seldom that an attempt is made to show that the physical characteristics of a given sampling location are appropriate to the problem being addressed with the data that are collected there. This may be because a coherent scheme has not been devised for classifying sites and relating their characteristics to intended data usage.

There is a great need for a site classification system since most monitoring stations will be expected to operate for many years, tens of thousands of dollars will be spent for equipment and installation, and further tens of thousands will be expended for maintenance and data processing during the period of operation. It would be foolish to locate a station where its data would not be appropriate to the intended uses. The costs of poor siting procedures can extend well beyond the actual costs of establishing and operating the stations. Whenever the data are used as a rationale for large-scale programs such as air quality improvement projects, there are likely to be great economic and social impacts, which means that the siting of data collection stations becomes even more important.

The uses of CO data can be broadly categorized as being related to the following:

- Enforcement of air quality regulations
- Development and evaluation of control measures
- Public health
- Scientific research
- Miscellaneous purposes.

Each of these broad categories contains several narrower subcategories of use, but at no level of classification is this system directly related to physical factors. In trying to devise a site classification system that can be used to define an appropriate set of physical characteristics for each site type, it seems reasonable to examine the uses of the data in terms of the physical factors that influence the data. For example, each of the above categories of use has a level of spatial smoothing that is appropriate for that use. Sometimes, the requirement is for many closely spaced measurements that will reveal small-scale features of the distribution of CO in space; at other times the

requirement is for measurements to typify a whole city or perhaps even a whole region of the country.

Those uses of data that are related to the development of air quality control measures illustrate the variety of spatial scales that can be of concern within a single, broad category of use. Measurements that are typical of a street canyon or a freeway corridor will be suitable for formulating control plans to reduce emissions along the specific roadway or along a limited number of similarly congested streets, but they will not necessarily be useful for the formulation of plans that are city-wide in scope. Plans of the latter type require data that represent much larger areas.

The concept of spatial representativeness arises from examples like those given above and provides a useful basis for classifying stations and the uses to which their data are put. Furthermore, it has a physical basis that can serve to define station characteristics. In general, the measurement scales that are of greatest importance are:

- Microscale, to define concentrations in volumes with dimensions of the order of meters to tens of meters.

- Middle scale, generally defining concentrations typical of areas with dimensions of tens to hundreds of meters. This category includes measurements to define concentrations along streets and roads and typical areas can be elongated, measuring tens of meters by hundreds of meters or even kilometers.

- Neighborhood scale, defining concentrations within some extended area of the city that has relatively uniform land use; dimensions are of the order of kilometers.

- Urban scale, to define the overall, citywide conditions on a scale of tens of kilometers; in general, more than one site will be required for such definition.

- Regional scale, to provide a measure of CO concentrations typical of a large, usually rural area of reasonably homogeneous geography and extending for tens to hundreds of kilometers.

Of course, the concept of scale can be extended upward to the global scale, but for this discussion, those scales enumerated above are sufficient. In fact, the discussion is limited to the middle, neighborhood and regional scales. Urban scale conditions, as noted, cannot be specified with measurements at a single location, but can be synthesized from measurements representing middle and neighborhood scales. When the latter two scales are well represented, it will not be necessary to find the ideal urban scale site. Microscale measurements are often made for very specialized research purposes that make a generalized set of siting requirements nearly impossible to devise. Factors other than scale of representativeness are important to the definition of types of monitoring site and their required physical characteristics. One of these other factors arises because virtually all routine CO monitoring is related directly, or indirectly, to health or public exposure and therefore samples taken at breathing level are most appropriate. Inlets at breathing level will constitute an obstacle in many locations and will also be subject to vandalism. Ott (1975) has suggested 3 m ± 0.5 m as a compromise and that same height range has been adopted here.

The adoption of the same inlet height as recommended by Ott provides consistency. Consistency, in turn, allows data from different locations to be compared with the assurance that any differences in the data sets will reflect something other than anomolous site characteristics. The site standards that Ott (1975) proposed were derived from a combination of empirical evidence and practical requirements. The representativeness concept, not surprisingly, leads to similar results so that consistency between the recommendations of this study and those of Ott is maintained.

In proceeding from the concept of spatial representativeness to the concrete requirements of siting, some arbitrary decisions are required; these decisions are made easier if they can be translated into very simple quantitative terms. The most pervasive of the translations that were used provided equivalence between the contribution that a specific source makes to observed concentrations at a monitor and the distance to that source. From this relationship, maximum allowable contributions (in mg/m^3) could be converted to minimum separations (in m) between the monitor and certain kinds of sources. For instance, regional sites should be far enough removed from cities so that the concentrations arising from emissions within the city will be less than typical rural background concentrations of 0.2 mg/m^3. Similarly, neighborhood sites should not be so close to large roadways that the emissions from the roadway increase measured concentrations more than about 1 mg/m^3. Because smaller roadways are less important contributors to the overall neighborhood concentrations, they should be permitted even less influence on the observed concentrations.

The relationships between minimum separation distance, source to monitor, and the maximum concentration impact of the source on the monitor can be derived from common diffusion equations. The physical requirements of the major site types are summarized below. These requirements have been derived according to the principles outlined above and are described in much greater detail in the body of this report.

Street Canyon Monitor

Ott type:	"A" - downtown pedestrian exposure station.
Scale of representativeness:	Middle
Inlet location:	3 ± 0.5m, over center of sidewalk, but at least 2 m from building front and 10 m from intersection.
Other requirements:	Street canyon width and depth should be typical of others in the area. Traffic should be either average or maximum for the area, depending on intended data use. Avoid bus stops, loading zones and other unusual source areas. Traffic counts would be valuable. Orientation relative to wind directions, use of multiple inlets, and the importance of one-way streets and daily traffic cycles are discussed in the text (Section III).

Traffic Corridor Monitor

Ott type:	None comparable
Scale of representativeness:	Middle
Inlet location:	3 ± 0.5 m, at edge of right-of-way, or at typical distance to nearest residences.
Other requirements:	Roadway should be at grade-level and as typical of its type as possible. Site should be well removed from intersections and overpasses or other large obstructions. Traffic counts and wind measurements would be valuable. Orientation relative to wind directions and the use of multiple inlets are discussed in the text, as are nongrade-level roadways (Section III).

Neighborhood Monitor

Ott type:	"C" - Residential population exposure station.
Scale of representativeness:	Neighborhood
Inlet location:	3 ± 0.5m. 35 m from nearest traffic.* 2.5 km from nearest major roadway, 50,000 vehicles per day or more.
Other requirements:	Reasonably homogeneous land use within 1 or 2 km of the site. Large cities, of diverse land use, should probably have enough stations of this type to characterize the variety of neighborhoods in the town. Traffic counts on nearby streets and wind measurements would be valuable.

Regional Monitor

Ott type:	"E" - Nonurban background stations.
Scale of representativeness:	Regional
Inlet location:	3 ± 0.5 m. Small vertical gradients make heights of up to 10 m acceptable in such locations if absolutely necessary. 35 km from nearest city, in the direction that is least frequently downwind; if more than one such station is planned, see Section III for preferred directions. 5 km from nearest major roadway -- 50,000 or more vehicles per day. 400 m from nearest traffic.
Other requirements:	Should not be aligned with any long straight section of a major roadway. Low-lying areas, subject to cold air drainage and stagnation should be avoided. Wind measurements are desirable.

---

* Ott (1975) specifies a minimum distance of 100 m to nearest street with more than 500 vehicles per day, but this seems unduly stringent.

The above summaries of the physical characteristics of the most important types of monitors make mention of traffic on certain roadways, of homogeneity of land use, and of other considerations that imply that it is not sufficient to simply place an inlet at 3 m height at some arbitrary location. In general, some areas are preferable to others, and within the preferred areas there are some specific sites that are better than others. Step by step procedures for site selection are described in Section III. The first step is usually to gather traffic data, land use data, topographic maps, and climatological information. Sources of these kinds of information are discussed in appendices to this report. The information is used to identify generally desirable areas, and reduce their numbers and their size until a final selection is carefully made. When this has been done, the data should be reasonably representative of the desired conditions.

The original premise that served as a basis for categorizing the sites and defining their physical requirements was that the purposes for data collection could be classified according to appropriate scales of representativeness. It was suggested, for example, that air quality improvement measures should be consistent in scale with the measurements that inspired them. This premise has been tested by simple calculations and it appears to be valid.

The simple diffusion model described in Appendix A was applied with a wide variety of meteorological data and some reasonable, idealized, urban distributions of CO emissions. The results show that a street canyon monitor on a typical, heavily traveled street will measure concentrations that are strongly influenced by the local traffic. In fact, it appears that more than half of the time the adjacent street will contribute over one-third of the observed CO. Such results suggest that observations are substantially influenced by emissions within a few blocks of the monitor (and that control plans should be designed accordingly).

As is to be expected, neighborhood stations are not so dramatically influenced by sources in their immediate vicinity. In fact, the siting criteria specifically seek to exclude such influences. However, the influences of sources within a few kilometers should be important if the scale of representativeness of the measurements is to be used to suggest appropriate scales for practical applications. The model from Appendix A was again used to estimate the region of influence. It was found that in most instances, the contribution of sources within 2 km of the monitor was more than one-third of the total, again demonstrating a reasonable relationship between the scale of representativity of the measurement and the appropriate scales for interpretation and application of the data.

In summary, the guidelines presented here should serve as a good basis for selecting sites that can be classified into a limited number of comparable types. The standardization of physical characteristics will ensure that comparison among sites of the same type will not be clouded by anomolies in the data, arising from peculiarities in the siting. Furthermore, the guidelines are sufficiently consistent with those already proposed by Ott (1975) that there should be little difficulty in combining the two schemes.

Use of the classification scheme does more than ensure compatibility of data; it also provides a physical basis for the interpretation and application of those data. This should help to prevent mismatches between what the data actually represent and what they are interpreted to mean. If carefully considered selection of monitoring sites could prevent one instance where a large-scale control plan is designed to cure a small-scale problem, then that alone would probably justify the effort required for proper selection of monitoring sites.

I INTRODUCTION

A. Monitoring Site Standards

As the importance of air pollution increases, so does the necessity to measure the concentrations of important pollutants in the air. Many reasons for making the measurements are discussed later in this report; they include attempts to understand pollutant behavior in the atmosphere, assessment of the effectiveness of control measures, and assessment of public health effects. Each purpose is best served by some combination of monitoring site characteristics. This report is an attempt to codify the monitoring site characteristics suitable for each of a variety of monitoring purposes and to provide procedures for selecting sites with characteristics optimum to the intended purposes.

The need for such codification and selection procedures can be illustrated with a few examples. If we wish to use measurements to estimate the public health effects of carbon monoxide (CO), the measurements must be made in areas where concentrations are representative of those to which the public is exposed. In many instances, the air has been sampled for this purpose at heights where the public has no access. Any vertical gradients of concentration will greatly reduce the usefulness of such data. Intercity comparisons of air quality must be based on data from comparable stations, which means that some station classification scheme will be required to judge the degree of comparability of the stations. Ott (1975) has shown that the range of average CO concentrations from four different locations in a single city, New York, is greater than the range of the measurements for 79 other sites in locations throughout the rest of the country. In fact, the range within New York was almost twice that of all the other sites. New York is not unique in this respect. In any large city there will be locations with widely differing concentrations, many of which are not representative of the city's general air quality. In fact, the diversity of measured concentrations and the diversity of land use suggest that there may be no one station that is representative of the entire city. Therefore, stations should probably be chosen to represent various aspects of the city's CO concentration distribution.

The preceding examples were presented only to illustrate a need for logical, consistent procedures that can be used to locate and categorize CO monitoring stations. The remainder of the report discusses various aspects of that topic.

B. Philosophy of Approach

An inspection of the interpretations given to concentration data reveals that the measurements are assumed to represent areas and volumes that extend well beyond the small volume that is actually sampled. The area presumed to be represented by a measurement may be relatively small, such as one side of a downtown street canyon; intermediate in size, like a neighborhood; or much larger, like a city, or even a whole region of the country.

The methods for locating stations that have evolved during this study have been based on the premise that the major purposes of establishing a certain monitoring site can be identified and then paired with a scale of representativeness that is most suitable for those purposes. Thus, the site selection process begins by identifying the purpose of the monitoring. Then, this purpose provides a basis for selecting a station type, based on the area that the measurements should represent. Finally, procedures are followed that lead to sites that represent areas of the appropriate size.

Although the site selection procedures are simple, they require labor. It is inconsistent to locate a monitoring station that will be expected to operate for many years, and will cost tens of thousands of dollars for instrumentation and facilities without commensurate expenditure of effort toward site selection. Furthermore, the measurements made at the monitoring site may serve as the basis for large-scale air quality improvement plans with enormous economic or social impact, again dictating a careful site selection process.

All costs and potential costs associated with monitoring stations warrant the expenditure of considerable effort in the site selection process. Thus, we have not hesitated to recommend the acquisition and interpretation of a diverse body of background information. In some instances, special measurements are warranted before making a final decision. The importance of the task demands that it be given time and thought.

C. Special Characteristics of Carbon Monoxide That Affect Monitoring Site Selection

Some of the special characteristics of CO as an air pollutant will limit the things that can be done in the siting of monitoring stations. Other CO characteristics will allow approaches that might not be possible with other pollutants. Fortunately, the limitations and special requirements imposed by the nature of CO sources can, in many instances, be met through exploitation of the relatively inert properties of the gas.

Table 1 summarizes the nationwide emissions for 1970. On a nationwide basis, transportation sources accounted for nearly three-fourths of the total and motor vehicles for nearly two-thirds. In urban areas the relative contribution is probably greater since several of the other major source categories (e.g., agricultural burning) take place almost entirely outside of the urban areas).

Table 1

NATIONWIDE ESTIMATES OF CARBON MONOXIDE EMISSIONS (1970)

Source: Cavender, Kircher and Hoffman, 1973

Source Category	Emissions, 10^6 tons/year	Percent of Total
Transportation	111.0	74.5
Motor Vehicles	96.6	64.8
Gasoline	95.8	64.3
Diesel	0.8	0.5
Aircraft	3.0	2.0
Railroads	0.1	0.1
Vessels	1.7	1.2
Other nonhighway use of motor fuels	9.5	6.4
Fuel combustion in stationary sources	0.8	0.6
Coal	0.5	0.3
Fuel oil	0.1	0.1
Natural gas	0.1	0.1
Wood	0.1	0.1
Industrial process losses	11.4	7.7
Solid waste disposal	7.2	4.9
Agricultural burning	13.8	9.3
Miscellaneous	4.5	3.0
Forest fires*	4.0	2.7
Structural fires	0.2	0.1
Coal refuse burning	0.3	0.2
Total	149.0	

* Includes prescribed burning.

The fact that motor vehicles constitute the largest urban source of CO means that most CO emissions take place near ground level along roadways. This, in turn, means that the sources and the public, or the monitoring station, can be very close to each other; therefore, the public or the monitor can easily be exposed in areas where little dilution has taken place. This contrasts with some other pollutant that may be emitted well above ground level, or may form slowly from chemical reactions in the atmosphere; such pollutants may not appear at locations accessible to the public until considerable mixing and dilution has taken place.

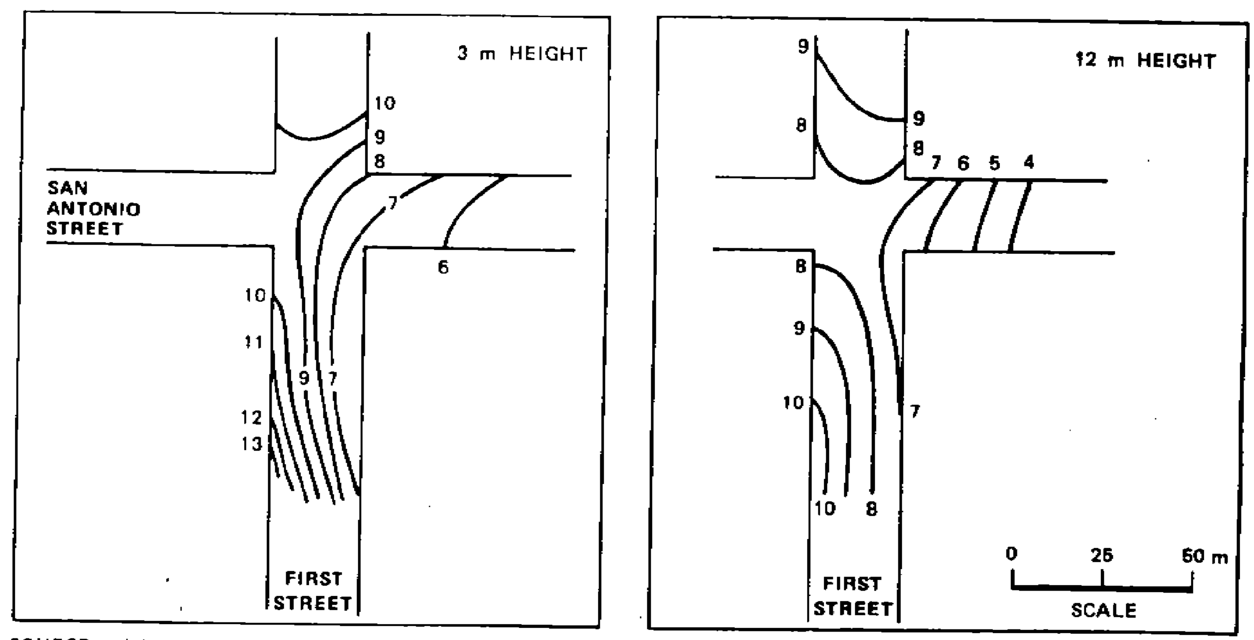
The nature of the CO source means that very large concentration gradients can be found near ground level, especially by streets or roads. Figure 1 illustrates this. It shows that concentrations at 3 m above a downtown street can change by several parts per million (or a factor of nearly 2) over distances of only a few tens of meters. If we were trying to represent the exposures of pedestrians, measurements made on either side of the street would be misleading if they were interpreted as applicable to all pedestrians on both sides of the street. The problem is to devise methods for taking measurements that are more representative, whatever purposes are being pursued.

Fortunately, the relative inertness of CO allows us to recommend procedures and techniques that can increase representativity but which would not be possible to use for many other pollutants. Much longer lengths of inlet tubing can be used for CO sampling than would otherwise be the case, because of it low reactivity. This, in turn, means that it is feasible to draw air to a single sampler from several separate points. If care is taken to equalize the flow from the different inlets, such samples can give an average concentration from opposite sides of the street and provide a number that is more representative of the exposure experienced by the total pedestrian population in the area. The use of multiple inlets to average concentrations from different parts of an area will overcome some of the problems posed by the large gradients in the vicinity of strong ground-level source areas.

D. Organization of This Report

The purpose of this document is to provide procedures for locating CO monitoring sites. As noted before, it is our opinion that the first step in such procedures must always be the determination of the primary purposes for which the monitoring is to be conducted so that the site can be classified and its physical requirements can be identified. Section II of this report discusses monitoring objectives and a site classification system that can be used to relate the objectives to the physical characteristics of the site.

Section III gives step-by-step procedures for selecting sites in the most important measurement categories. Section III is intended as the working part of the report.



SOURCE: Johnson et al.

SA-3516-24

FIGURE 1 MEASURED HOUR-AVERAGE CO PATTERNS AT TWO HEIGHTS FOR A SAN JOSE, CALIFORNIA INTERSECTION DURING LATE AFTERNOON ON 11 DECEMBER 1970

The site selection procedures would not be valid if there were no rational quantitative reasons for them. Section IV is included to provide the reasoning that was used to arrive at the suggested site selection methods, particularly the limiting values that are suggested for such things as inlet height, separation distances between sources and inlets, and so forth.

In some of the recommended procedures, the person making the site selection decision will have to use unfamiliar data. The appendices provide some discussion of these different kinds of data and possible sources from which they might be obtained. A simple model that can assess the relative contributions of sources at different distances is also discussed and a program listing and user instructions are given.

Finally, a bibliography is included to show the diverse uses of CO (and in some cases, other pollutants) data. The bibliography also includes a sampling of citations dealing with monitoring and siting philosophies and procedures.

II DECIDING THE TYPE OF CO MEASUREMENTS THAT ARE TO BE MADE

A. Uses of Carbon Monoxide Measurements

The objective of this section is to present a unified theme for classifying monitoring stations. Our approach to this objective has been to start with a simple list of the uses of ambient CO concentration data, which was compiled by searching the literature for reports and papers that made use of such data (see Appendix E). The ways in which the data had been used were assembled and listed without regard to their relative importance or to the possible overlapping of objectives. In the list that follows we have tried to group the purposes into general categories:

1. Enforcement of Air Quality Regulations

   - Determine compliance with air quality standards:

     - Federal primary
     - Federal secondary
     - State or local.

   - Provide information for preparation of environmental impact statements:

     - Highway projects
     - Transportation plans
     - Large developments
     - Indirect sources.

2. Research

   - Determine relations between concentrations and sources (or sinks):

     - Specific emitters
     - Emissions related to land-use patterns, etc.
     - Indirect sources, shopping centers, stadiums, etc.
     - Classes of emitters, e.g., vehicular, stationary, etc.

   - Provide information for better understanding of the processes affecting CO concentrations:

     - Subjective understanding

- Objective modeling: development, evaluation, and refinement.

- Describe the "microdistribution" of CO in special areas:
  - Intersections
  - Street canyons
  - Tunnels
  - Below-grade highways.

- Provide measurements of the magnitude of sources and sinks:
  - Anthropogenic
  - Biological.

- Test monitoring equipment.

- Evaluate interstate and international transport processes.

- Provide measurements of natural, worldwide background CO concentrations.

3. Development and Evaluation of Controls

- Evaluate results of control measures
  - "Hot spots"
  - Overall urban conditions
  - State, regional, or nationwide conditions.

- Determine long-term trends in CO concentrations:
  - In an urban area
  - In a rural area
  - Worldwide background.

- Provide information for city and regional planners and decision-makers.

4. Public Health

- Alert authorities to existing or impending critical situations.

- Evaluate the effects of human exposure to ambient CO.

- Determine the relationship of ambient outdoor CO levels and those inside buildings.

5. **Miscellaneous**

- Provide information for comparisons among locations and areas of the same general class:

  - City streets
  - Neighborhoods
  - Urban regions
  - Larger regions.

- Evaluate representativeness of existing and proposed monitoring sites.

The above list is quite diverse and it is not immediately obvious that any coherent, physically sound, applicable taxonomy exists. We are indebted to a paper by Dr. Wayne Ott (1975) that provided much of the stimulation for the following analysis.

Since the goal is to devise a set of physical characteristics and procedures for selecting monitoring sites, it seems reasonable that the objectives should be related to a physical classification scheme. Spatial scale of representativeness has been chosen as the basis for the classification system. As noted before, any useful measurement of CO concentration is supposed to represent some volume and some period of time. Actually, the measurements always involve averaging over some period of time because the analyzed volume is collected over a finite period; at the same time, spatial averaging occurs over the same volume. In general, this volume does not correspond to the objectives of the monitoring. The objectives may require representation of volumes considerably different from those from which the samples are drawn. Site selection, when viewed from this perspective, consists of selecting a location or locations where concentrations in the volume that we sample can be related to concentrations representative of the volume that is required to meet our objectives.

B. Spatial Scale of Representativeness

The categories for classifying the various objectives are listed below. They are presented in order, from the smallest scale to the largest scale of measurement. Their relative importance will be discussed later.

1. Microscale

This refers to volumes with dimensions of meters to a few tens of meters, smaller than downtown street canyons or below-grade highways. Those special studies attempting to determine CO distributions within parking lots, within street canyons, over highways, and the like require microscale measurements. Similarly, the development, testing, and revision of models that seek to describe the processes that produce these concentration distributions require data of this scale. This type of measurement might also be used to define health effects for certain individuals, such policemen, who remain near a fixed location for extended periods.

2. Middle Scale

This category covers dimensions from tens of meters to hundreds of meters and more. In certain cases discussed below we apply it to regions that may have a total length of kilometers. In many cases of interest, sources and land use may be reasonably homogeneous for long distances along a street, but very inhomogeneous normal to the street. This is the case with strip development, freeway corridors, and downtown street canyons. We have included in this category measurements to characterize the CO concentrations along the urban features just enumerated.

When a site is chosen to represent conditions in a single street canyon or a block of strip development, then the characteristic dimensions of this scale are tens of meters by hundreds of meters. If we try to characterize street canyon conditions throughout the downtown area, or along an extended stretch of freeway, the dimensions may be tens of meters by kilometers.

Public health effects and air quality standards related to public health effects would use measurements of this scale for their assessment. People moving through city streets tend to be exposed to CO concentrations consistent with a scale like this. This is also a scale of measurements that would provide valuable information for alerts, for devising and evaluating "hot spot" control measures, for comparing central business districts in different cities, and for providing the outdoor measurement necessary to the study the relationship between outdoor and indoor concentrations in large public buildings.

This important class would also include the characteristic concentrations for other areas, with dimensions of a few hundred meters, such as the parking lot and feeder streets associated with indirect sources--that is, complexes that are not themselves pollutant emitters, but which attract significant numbers of pollutant emitters, particularly autos. Shopping centers, stadia, and office buildings are examples of indirect sources.

3. Neighborhood

Measurements in this category would represent conditions throughout some reasonably homogeneous urban subregion, with dimensions of a few kilometers and generally more regularly shaped than the middle-scale. Homogeneity refers to CO concentration, but it probably also applies to land use. In some cases, a site carefully chosen to provide neighborhood-scale data, might represent not only the immediate neighborhood, but also neighborhoods of the same type in other parts of the city. These kinds of stations would provide information relating to health effects and compliance with regulations because they would represent conditions in areas where people live and work.

Neighborhood-scale data would provide valuable information for developing, testing, and revising concepts and models that describe the larger-scale concentration patterns, especially those models relying on spatially smoothed emission fields for inputs. These types of measurements could also be used for interneighborhood comparisons within, or between, cities. This is also the most likely scale of measurement that would meet most of the objectives of city and regional planners and decision-makers.

4. Urban

This class of measurement would be made to typify CO concentration over an entire metropolitan area. Such measurements would be useful for assessing trends in city-wide air quality and, hence, the effectiveness of larger-scale air pollution control strategies. Measurements that represent a city-wide area would also serve as a valid basis for comparisons among different cities.

5. Regional

These measurements would characterize conditions over areas with dimensions of as much as hundreds of kilometers. As noted earlier, representative conditions in an area imply some degree of homogeneity in the area. For this reason, the class of regional measurements would be most applicable to sparsely populated areas, without major settlements. Data characteristic of this scale would provide information about interstate transport processes.

6. National

Measurements that defined concentrations on this scale would characterize the CO level of the nation as a whole. Characterizing national CO levels would provide trend data and allow assessment of national policies. Such data would also be useful for studying international and global transport processes.

7. Global

Such measurements would provide information useful to the identification of world-wide trends in CO concentration.

The above list categorizes measurements according to the spatial scale to be represented. Virtually all uses of CO measurements involve the characterization of CO concentration on one or more of these scales. Some scales would be difficult, and perhaps impossible, to represent with a measurement at a single site. Thus, there need not necessarily be a site category that corresponds to each of the above scales of measurement; some scales will have to be represented as a composite of measurements characterizing smaller areas.

C. Relative Importance of the Different Scales of Measurement

Some of the scales of measurement will be more important than others for at least two reasons. One of these is the number of separate purposes that can be served by a particular scale. The other reason is based on a judgment of the relative importance of the purposes that are served. Most continuing measurements of pollutant concentrations are used to define air quality, particularly as it relates to the national primary ambient air quality standards. Accordingly, we have chosen to emphasize those scales of measurement that are most closely related to those standards.

The national primary ambient air quality standards are "those which, ... based on the air quality criteria and allowing for an adequate margin of safety are requisite to protect the public health." (Federal Register, 1971). The emphasis on public health gives the air quality standards great importance. The emphasis on public exposure is further shown by the definition of ambient air that is used in connection with the air quality standards: "Ambient air is that portion of the atmosphere, external to buildings, to which the general public has access." If we accept ambient air quality standards as the major motivation for monitoring, then the ranking of scales of measurement can be carried out so that the most important scales are those which are most characteristic of the kinds of exposures that the general population encounters. Although the air quality standards must be met on all scales, the emphasis on public health and public exposure is apparent in the definitions quoted above, and hence it seems reasonable that site selection should be subject to the same emphasis. Finally, experience has shown that areas of greater public exposure are more likely to experience standards violations than are areas that contain few people. With such factors in mind, the following ranking was developed:

(1) Neighborhood
(2) Middle
(3) Urban
(4) Regional
(5) Micro
(6) National
(7) Global

As noted in the discussion of the various scales of measurement, most people are exposed to CO concentrations on the neighborhood or the middle scale. Thus, these two scales should occupy the most important positions in the list. Many people, over a period of a day or week, will be exposed to neighborhood and middle scale concentrations of CO. A mixture of such exposures can be considered as representative of the urban environment as a whole, and hence the relatively high ranking of urban scale measurements.

Since it would be virtually impossible to represent the hodge-podge of neighborhood and middle-scale concentrations with measurements at a single site, no "urban-scale" measuring station is described in spite of its acknowledged importance. We feel that urban areas must be characterized by networks of stations that describe the range of conditions within the area.

Another large segment of the population dwells in areas that could be characterized by regional-scale measurements; therefore, this scale also deserved a high place on the list. It ranks lower than the urban scale because "regional" areas will be rural and have lower concentrations of both CO and people. Therefore, they are likely to be less critical.

Since the microscale measurements are, as noted before, of importance in determining the health effects on only a very limited class of citizens, it will usually be adequate to rely on middle-scale measurements for the protection of this group. Other reasons for relegating this category to fifth place are discussed later. The final two categories, national and global, are representative of such large areas that they do not relate to the exposure of the public. There are also other grounds, which are discussed later, for placing these categories at the end of the list.

The ranking of measurement scales given above, which is based specifically on the requirements of national air quality standards, is the same ranking that would have resulted if the primary rationale had been public health, because public health is the rationale for the primary air quality standards.

The needs of urban diffusion modelers are best met by the first two scales listed (neighborhood and middle) because the models generally use emissions inventories of these scales to predict concentrations on the same scales. Regional measurements will provide the data necessary for evaluating the performance of models that are designed to describe larger-scale transport processes.

Preparation of environmental impact statements is becoming an increasingly important activity that requires CO concentration data. Since one of the motivations for the preparation of these statements is to define present air quality, and the potential changes in that air quality as they relate to air quality standards, it is not surprising that the most important scales of measurement for evaluating environmental impact are much the same as shown in the above list. The CO impacts of indirect sources are felt most on the middle- and neighborhood-scales. Conceivably, very large projects could have urban-wide or regional CO impacts but CO is not likely to be the worst pollutant in such instances.

Our survey of the literature suggests that those making microscale measurements of CO concentration have specialized requirements that would be difficult to generalize. The users are usually research oriented and develop their own criteria, carefully matched to their own specific aims. The usual requirements associated with microscale measurements tend to be beyond what we consider to be the primary scope of this report—to provide guidelines for siting the more routine, long-term monitoring stations.

Finally, the last two categories on the list can be relegated to the end because they are largely redundant. To some extent this is also true of the urban scale. If the middle- and neighborhood-scale measurements have adequately characterized the city's downtown streets, shopping centers, highway corridors, and neighborhoods, then all the necessary information is available for characterizing the city as a whole. Similarly, if the cities and regions are adequately described, their descriptions can be synthesized into a national description and on to the global scale.

The conclusion of the above discussion is that the most important specific site types can be associated with three scales of measurement:

- Middle
- Neighborhood
- Regional.

The site selection process begins with an identification of the appropriate scale of measurement, which is discussed in the next section.

D. Selecting the Required Scale of Representativeness

Table 2 summarizes the most important of the purposes for which measurements may be made and the relationships between the scales of measurement. If the relationships were unambiguous and there were only one scale that were suitable for a given purpose, it would only be necessary to find the measurement purpose in the first column, see which one of the other columns contains a check mark, and proceed to the appropriate part of Section III of this report.

In some instances, the ideal case described above is the one that prevails, but most often, some subjective decisions are required. Before proceeding to a discussion of the many less than ideal cases represented in the table, note that the middle-scale class of measurements has now been subdivided into three special subtypes.

(1) Downtown street canyon—Middle-scale measurements to define the CO concentrations along streets in areas of dense, multistory buildings.

(2) Indirect source--Middle-scale measurements to define the CO concentrations prevailing outdoors along walkways, in parking lots, and on streets surrounding so-called indirect sources that do not emit pollutants themselves but they do attract pollutant emitters, particularly automobiles. Examples include, shopping centers, theaters, and stadia.

(3) Corridor—Middle-scale measurements to define the CO concentrations along major highway corridors, another kind of indirect source.

In Table 2, the kinds of measurement that will be required for a given purpose are indicated by an "X". An "X" enclosed in parentheses indicates that the needs might be satisfied, in particular cases, by temporary or mobile units. Blank spaces have been left where measurements of the designated scale are not usually very useful, although there will be exceptions. The purposes for which the measurement data are to be used are discussed on the following pages.

1. Determine Compliance with Ambient Air Quality Standards

It can be inferred from the air quality standards that the most important locations for such measurements will be those that combine the highest concentrations with the greatest exposures of population. Among the more likely locations for such a combination is the downtown street canyon, which has high traffic densities, confined spaces between buildings, and large numbers of people present. In the neighborhoods, concentrations may be less, but people spend greater periods of time exposed to them. Thus, high density residential neighborhoods are also likely candidates for stations devoted to this purpose. Indirect source sites are less likely to be required for this purpose, because of the lower frequency of instances where high concentrations are reached. Mobile monitors could be used to measure concentrations when scheduled events are expected to produce high traffic densities. Corridor measurements may be appropriate where residences are near heavily traveled highways.

2. Alert Authorities to Existing or Impending Critical Situations

Traffic jams are most likely to produce critically high pollutant concentrations in already congested downtown areas, around indirect sources, or along stretches of freeway. However, the latter two are poor candidates for permanent measuring sites devoted to this purpose because of the infrequent or erratic occurrence of such conditions at locations of those types. As noted before, indirect source monitoring for purposes of detecting high concentrations could probably be done best on an "as needed" basis with mobile equipment. Similarly, when severely congested conditions occur on freeways, mobile equipment might be brought to the scene via surface streets.

3. Evaluate Results of Control Measures

There are many possible control measures that could be evaluated. Some are essentially city-wide, such as transportation plan revisions or exhaust emission controls. For these, sites characterizing neighborhood concentrations are suitable because they will measure the results of the controls without being unduly influenced by large, unrelated fluctuations in local emissions. For specific, smaller scale

Table 2

SCALES OF MEASUREMENT APPLICABLE TO VARIOUS PURPOSES

Purpose	Applicable Scales of Measurement				
	Middle			Neighborhood	Regional
	Downtown Street Canyon	Indirect Source	Traffic Corridor		
1. Determine compliance with ambient air quality standards	X	(X)	(X)	X	
2. Alert authorities to existing or impending critical situations	X	(X)	(X)	(X)	
3. Evaluate results of control measures					
• Hot spots	(X)	(X)	(X)		
• City-wide				X	
4. Determine long-term trends					
• Urban	X		X	X	
• Rural					X
5. Provide information for developing evaluating and refining air pollution models	(X)	(X)	(X)	X	X
6. Provide information for comparisons among locations of the same general class, e.g.,					
• Street canyons	X				
• Highways			X		
• Neighborhoods				X	
• Rural areas					X

Table 2 (Continued)

SCALES OF MEASUREMENT APPLICABLE TO VARIOUS PURPOSES

Purpose	Applicable Scales of Measurement				
	Middle			Neighborhood	Regional
	Downtown Street Canyon	Indirect Source	Traffic Corridor		
7. Serve as data base for city and regional planners and decision makers				X	
8. Serve as data base for environmental impact statements, e.g.,					
• Highway projects			(X)	X	
• Transportation plans	X		X	X	
• Large developments				X	
• Indirect sources		(X)	(X)	X	
9. Provide measures of the magnitude of sources and sinks					
• Anthropogenic			(X)		X
• Biological					X
10. Provide measures of indoor/outdoor concentration relationships	(X)	(X)		X	

Note: X - Fixed site
(X) - Mobile or temporary site

control measures, monitors that will characterize the middle scale are more appropriate. The evaluation of some control measures on this scale will only require monitoring for a limited period of time, perhaps a week or two in different seasons. Among such control measures are traffic engineering changes that would improve traffic flow in the downtown area. Such control measures might require any of the three types of middle-scale measurement, depending on the facility to which they were applied.

4. Determine Long-Term Trends

Middle-scale measurements will not be as useful for this purpose as neighborhood-scale measurements because they are highly influenced by large, and often erratic, fluctuations in emissions over a relatively small area. When the emissions influencing a location are averaged over a larger area, then the fluctuations in concentration will more realistically reflect meteorological factors and changes in emissions that are more widespread than those that affect the middle scale. Therefore, the neighborhood- and regional-scale measurements are likely to be more suitable for evaluating long-term trends in CO concentration.

5. Provide Information for Developing, Evaluating and Refining Air Pollution Models

Inasmuch as air pollution models have been developed or proposed to describe phenomena on almost any scale, the measurements required by those models are apt to be of any of the scales. Usually, those models of smaller scale phenomena--for example, street canyon effects or distributions of CO in parking lots or along the edges of freeways--will use microscale or middle-scale measurements collected during programs devoted especially to the purpose.

Models describing the distributions of pollutants throughout the urban area will often make use of available data bases from stations that are tacitly assumed to represent conditions on the neighborhood scale. Generally, the appropriate scale of measurements to be used for model validation studies is approximately the same level of detail as is used for the emissions inventory that serves as an input to the model.

6. Provide Information for Comparisons Among Locations of the Same General Class

Often it is desirable to compare CO concentrations in different neighborhoods in the same city, or similar neighborhoods in different cities. In such instances, valid comparisons can only be achieved between measurements of comparable scales of representativeness. Similarly, conditions in the downtown street canyons of two different cities may be compared if appropriate data, representative of the street canyons, are available. Almost any kind of comparisons can be made, but they will have more meaning if the types of area represented by the measurements are known.

7. Serve as a Data Base for Planners and Decision Makers

The activities of regional planners and other officials making long-range decisions are usually on the neighborhood scale or larger. There are exceptions, such as traffic engineers who may be concerned with smaller scale phenomena, e.g., traffic flow in the central business district or congestion at specific intersections, but most long-range decisions are not concerned with small areas, short segments of individual streets, or localized activities, but with the distribution of business, industry, residences, and transportation throughout an area. If air quality measurements are incorporated into this level of the decision-making process, it will usually be on a large-scale, through the analysis of long-term trends or the use of urban air quality models.

8. Serve as a Data Base for Environmental Impact Statements

Very often, projects for which impact statements are required will affect air quality on the middle scale. If the area in which the project is to be located is reasonably homogeneous, then neighborhood-scale measurements can be used to characterize conditions prevailing before the project is begun. Sometimes it will be necessary to make special middle-scale measurements for the purpose. For example, if the project is a highway widening, then corridor-type measurements will be required in the area where the widening is planned. Similarly, expansion of a shopping area might require measurements of the concentrations around that indirect source in its unaltered configuration. Preparation of environmental impact statements will require measures of preproject conditions and data that will serve as bases for estimating the changes caused by the project.

9. Provide Measures of the Magnitude of Sources and Sinks

The magnitude of sources and sinks can be estimated from concentration and wind measurements on the upwind and downwind sides of the area in question. Comparisons of the fluxes will provide estimates of the magnitude of an intervening source or sink. Regional-scale measurements on the windward and leeward sides of a city might provide some estimates of its larger-scale impact as a source of CO. Emission rates from smaller sources, such as highways, can also be estimated from appropriate micro- or middle-scale measurements, but these usually involve special, nonpermanent facilities as indicated in Table 2.

10. Provide Measures of Indoor/Outdoor Concentration Relationships

Applications of this type will require special, nonstandard measurements; in particular, indoor observations will be required. The outdoor measurements may also include nonstandard locations to collect data representing CO levels near air conditioning inlets. Standard neighborhood scale measurements will probably be useful for studies of indoor/outdoor concentrations in residential buildings, but special middle scale measurements will be the rule for such studies with commercial buildings.

An evaluation of Table 2 suggests that the most important types of permanent stations are those that characterize neighborhood and regional scales and the type used for middle-scale concentrations in downtown areas and along traffic corridors. The following sections therefore emphasize sites appropriate to the representation of regional, neighborhood, city center and traffic corridor conditions.

III SELECTING STATION LOCATION

A. Background

The purpose of this section is to provide, as nearly as possible, step-by-step procedures for locating monitoring stations that will represent the three most important measurement scales discussed in the preceding section. The form and major steps of the site selection process are presented in flowcharts with accompanying discussion. To avoid obscuring the steps of the procedure, this section includes little justification for specific recommendations; this has been deferred to the next section of the report. Similarly, sources of the special data or analytical tools that may be required during site selection processes are not discussed extensively in this section; the appendices can be consulted for such information.

The different procedures to be used in selecting sites are presented below in an order that proceeds from large- to small-scale representation. This is the same order that would arise if the procedures were organized according to increasing complexity.

B. Regional Stations

Figure 2 is a schematic diagram of the site selection process for a regional-type station. The process reflects the fact that such stations may be used to estimate the CO concentrations entering an urban area. The selection process also reveals that siting criteria for the establishment of a single station will differ from those used for more than one station.

The site selection process begins with acquisition of the necessary background material. This material is to be used as a basis for the judgmental decisions that are required during the selection process. Two basic kinds of information are required: geographical and climatological. The geographical material is used to determine the distribution of natural features -- forests, rivers, lakes -- and the works of man. Useful sources of such information include: road and topographical maps, aerial photographs, and satellite photographs, particularly those from the Earth Resources Technology Satellite (ERTS). Naturally, the site selection process is one that winnows out unsuitable regions and proceeds to fewer and smaller areas. Thus, the photographs and maps will generally be used in an order that proceeds from those that depict large areas, such as shown in an ERTS photograph like Figure 3, to those that show smaller areas in greater detail, like the aerial photograph in Figure 4.

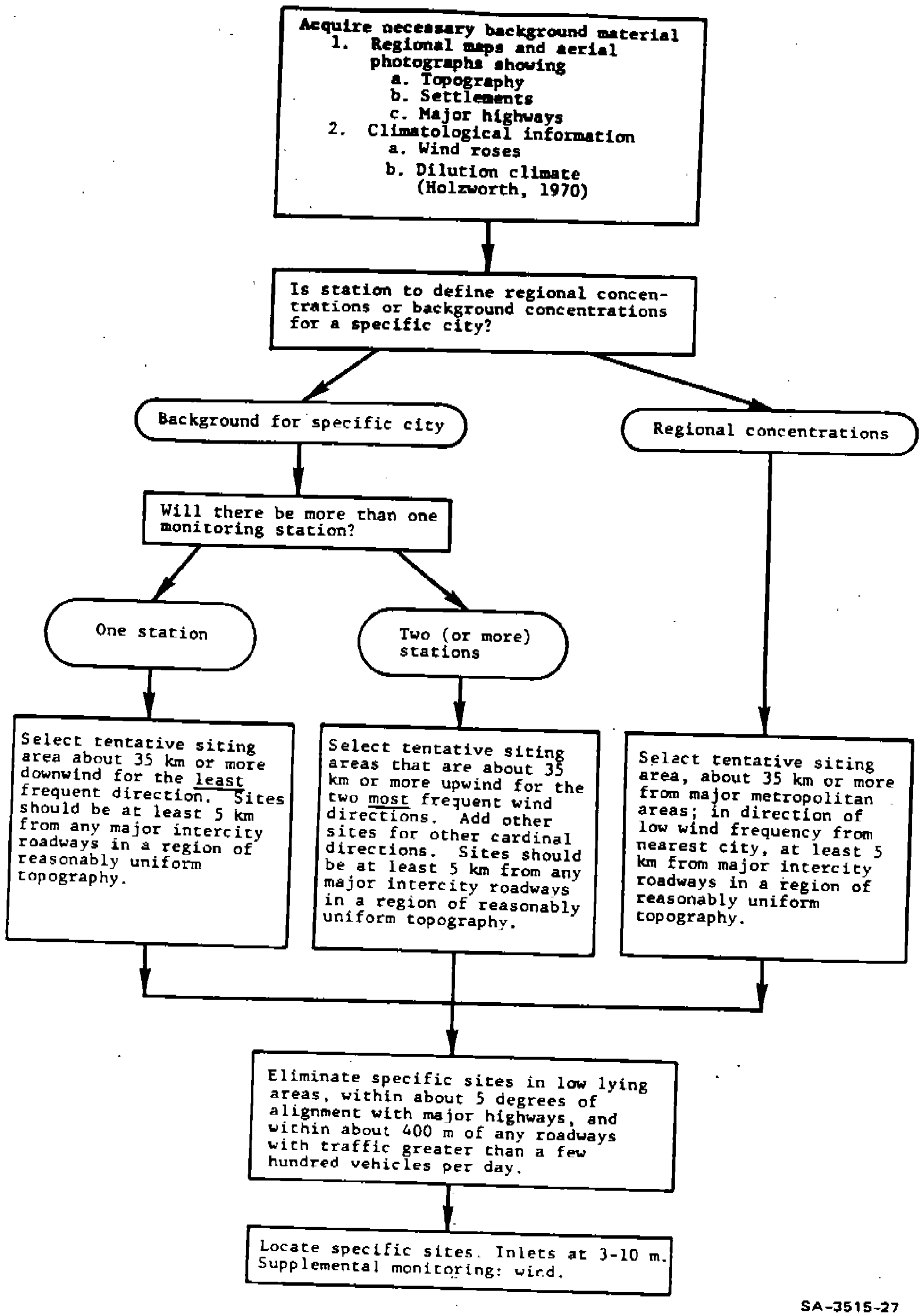
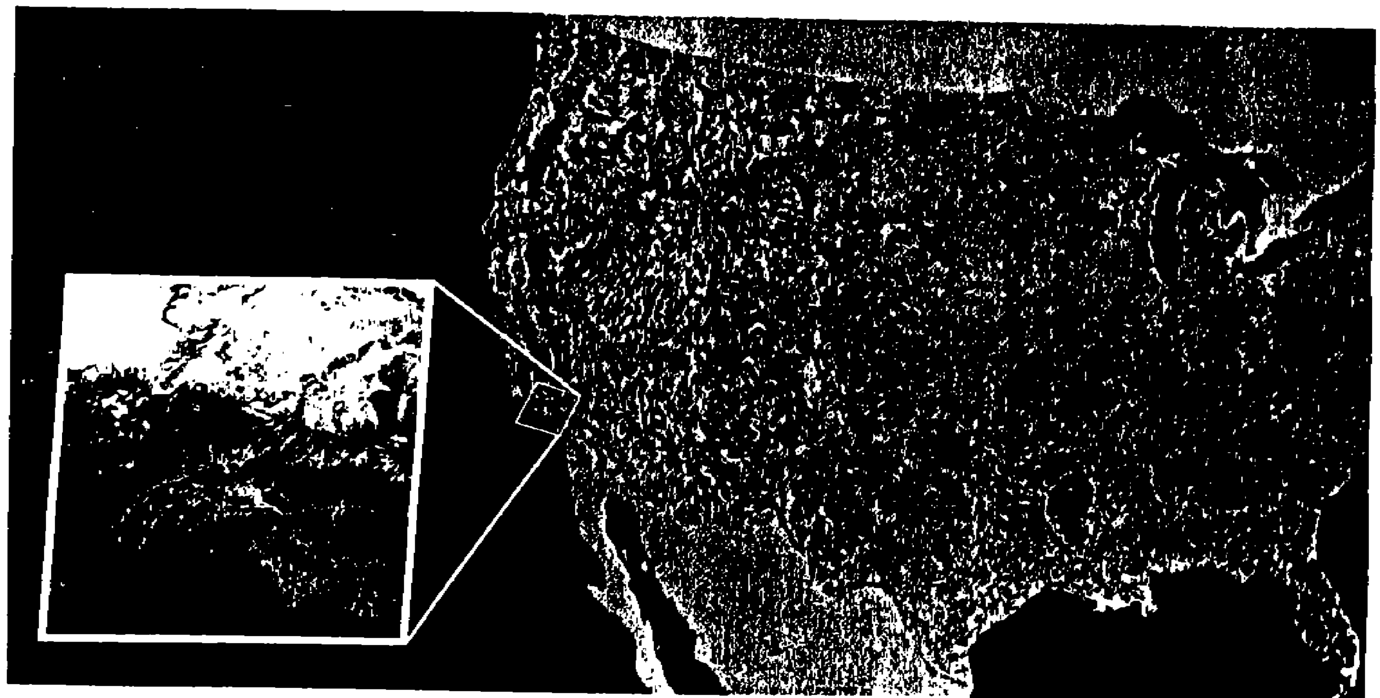


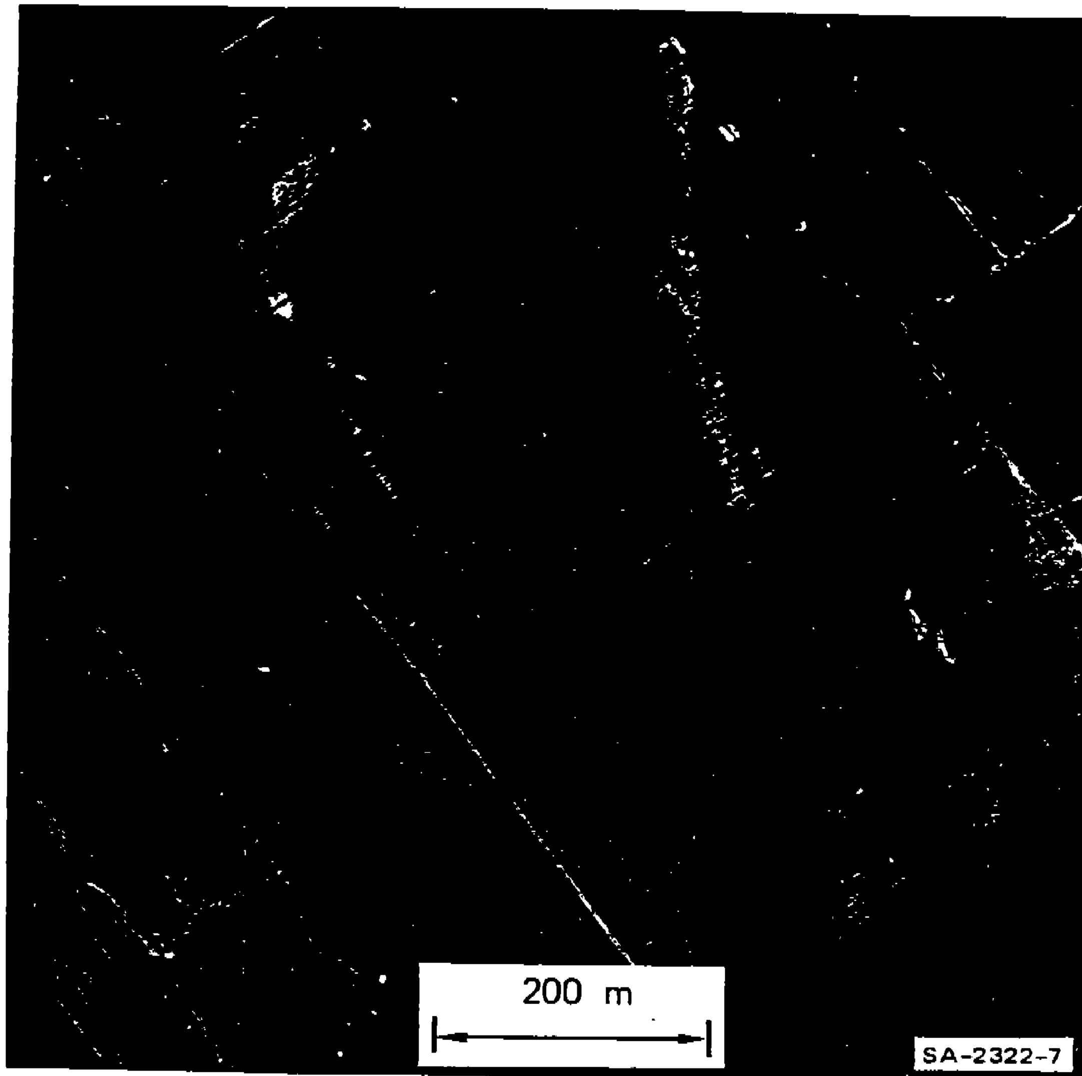
FIGURE 2 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING REGIONAL STATIONS



SOURCE: USGS INF-74-22 (R.1).

SA-3515-5

FIGURE 3 EXAMPLE OF EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS) PHOTOGRAPH AND A MOSAIC OF THE UNITED STATES



SOURCE Dabberdt and Davis, 1972.

FIGURE 4 AERIAL PHOTOGRAPH OF A RURAL AREA

The climatological summaries of greatest use are the frequency distributions of wind speed and direction. This information will usually come in one of two forms. One of these is a tabulated joint frequency distribution like that shown in Table 3, an example of the material that is available from the National Climatic Center. The wind rose is an easily interpreted graphical presentation of the directional frequencies. Examples of wind roses are shown in Figure 5, from the National Climatic Atlas (National Oceanographic and Atmospheric Administration, 1968). Other types of useful climatological data are also available but, generally, are not as directly applicable to the site selection process as are the wind statistics. These summaries are discussed in Appendix C.

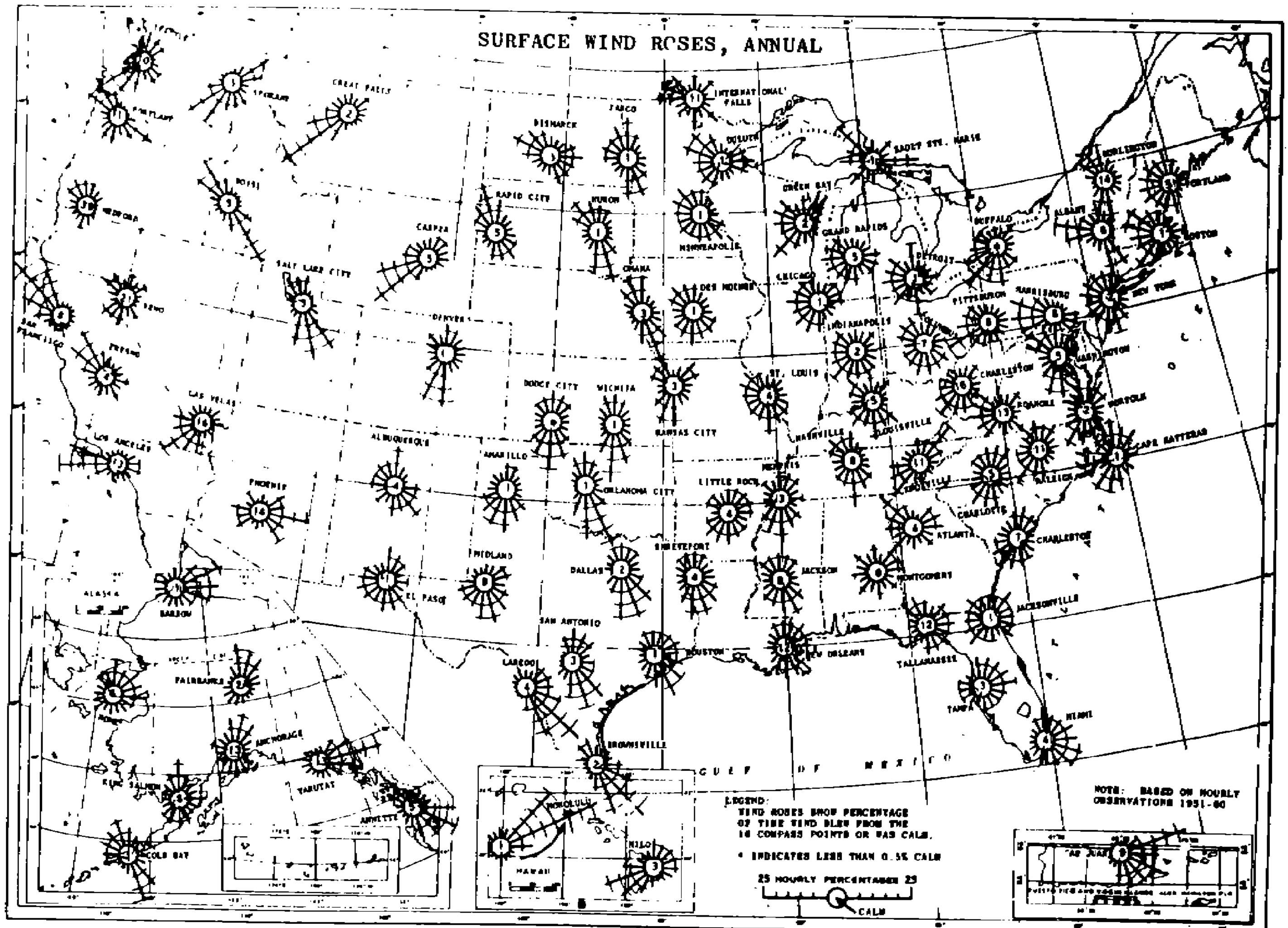
Table 3

EXAMPLE OF A TABULATED WIND SUMMARY

PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV. SPEED
	0 - 3	4 - 7	8 - 12	13 - 18	19 - 24	25 - 31	32 - 38	39 - 46	47 OVER	TOTAL	
N	+	1	2	1	+	+				4	11.4
NNE	+	1	2	1	+	+				4	10.5
NE	+	1	3	2	+	+				6	11.7
ENE	+	1	2	1	+					4	11.4
E	+	1	1	+	+					3	9.0
ESE	+	1	1	+						2	8.6
SE	+	1	2	1	+	+				4	8.9
SSE	+	1	2	1	+	+				4	11.0
S	1	2	2	3	2	1	+			10	13.3
SSW	+	1	1	3	2	1	+			8	14.4
SW	+	1	1	3	2	1	+	+		8	15.5
WSW	+	1	3	4	4	1	+	+	+	14	17.3
W	+	1	3	5	3	+	+	+		12	15.3
WNW	+	1	2	3	1	+	+			7	14.6
NW	+	1	2	2	1	+				6	13.1
NNW	+	1	1	1	+	+				4	12.0
CALM	+									+	
TOTAL	4	13	30	30	17	5	1	+	+	100	13.5

Source: National Climatic Center
Asheville, N. C.



SOURCE: National Oceanographic and Atmospheric Administration, 1968.

SA-3515-6

FIGURE 5 EXAMPLE OF WIND ROSES

After the background material has been assembled, a decision must be made regarding whether the monitor is to be used to supply information on CO concentrations that enter a specific city. For selecting a purely regional site, maps or satellite photographs should be used to identify general areas that are suitable for locating such stations. Uniform topography is desirable. The climatological information should be incorporated into the selection process to determine those areas which will be least frequently downwind of the closest major urban areas, especially during periods of low wind speed. If possible, the prospective siting areas should be at least 35 km from that urban area as illustrated in Figure 6. It also illustrates the fact that the siting area should not be within about 5 km of the nearest major intercity arterial.

The requirements for regional stations that will provide data on the background CO concentrations entering an urban area are much the same as for the purely regional site described above. In fact, if only one background station is being established, the requirements are identical. If more than one upwind urban background site is planned, then the potential siting areas should be chosen to be upwind for the two most frequent wind directions. Figure 7(a) illustrates this schematically. If the two most frequent wind directions are within 90 degrees of each other [Figure 7(b)], then the most frequent direction will be used, along with the most common direction from among all those that are more than 90 degrees different from it, as Figure 7(b) illustrates. Any prospective siting area should be more than 5 km from the nearest major intercity arterial road.

Once the general siting area has been selected, a winnowing process begins. Low-lying locations are unsuitable, as are sites that are located within about 5 degrees of alignment with extended straight highway segments, as shown schematically in Figure 8. The monitoring site should not be too close to any road that has more than a few cars per day traffic; specifically, no road with a few hundred cars per day should be within about 400 m of the site.

The monitoring site should be in an area, open sufficiently that the air is not likely to stagnate. In farmland or other open areas, this will be no problem. In a forested area, a clearing would be desirable; if none is available, then the inlet could be raised a few meters above the tops of the surrounding trees. In most instances, the inlet height at the site finally selected can be between about 3 and 10 m above the surface although 3 m is the most desirable. Figure 9 illustrates a typical site that might be used for regional CO monitoring.

A CO monitoring site can also be used for measuring other environmental factors that are related to the air pollution problem. In particular, winds are quite important, and they should be measured at a height of about 10 m above the general level of the surrounding surface.

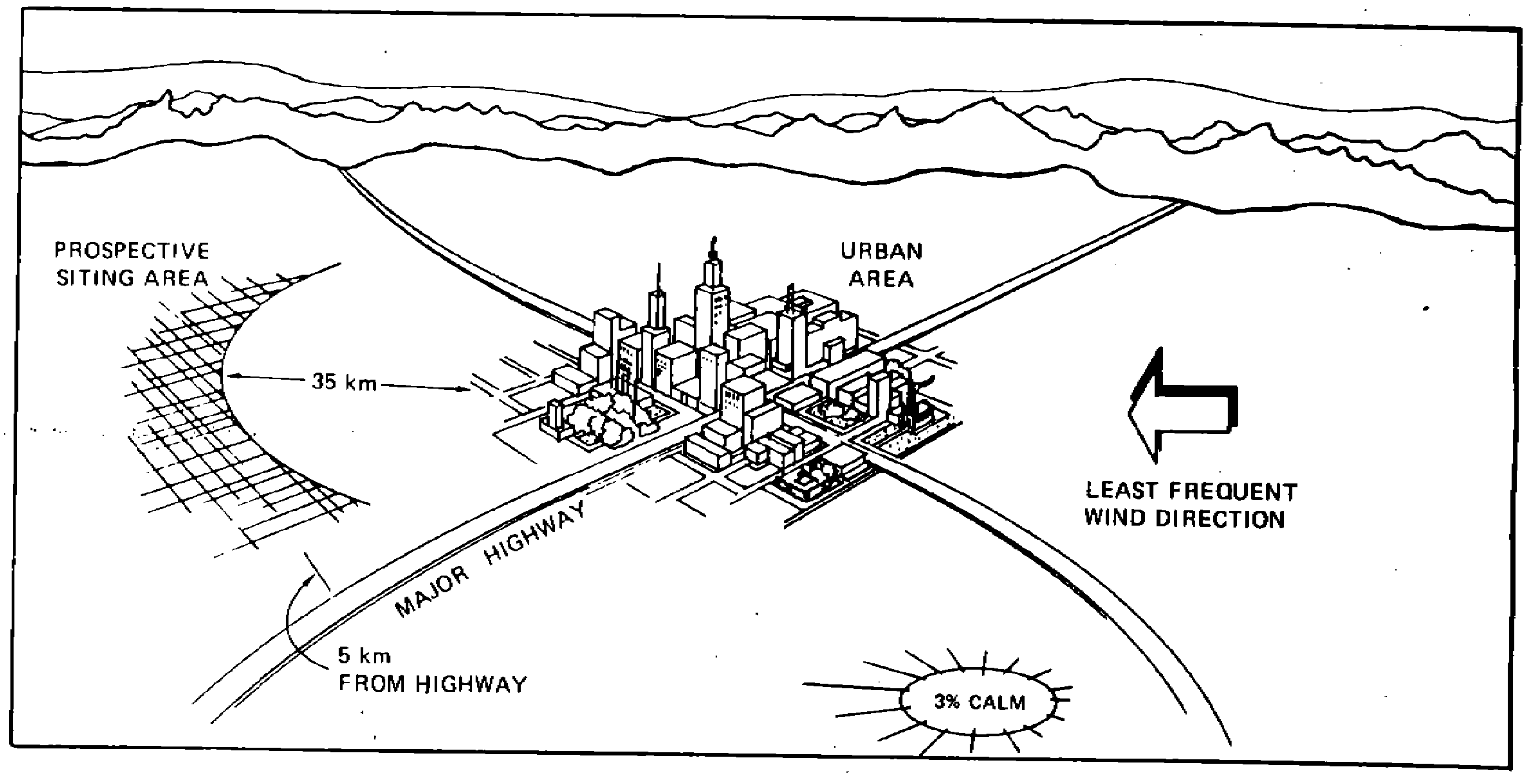
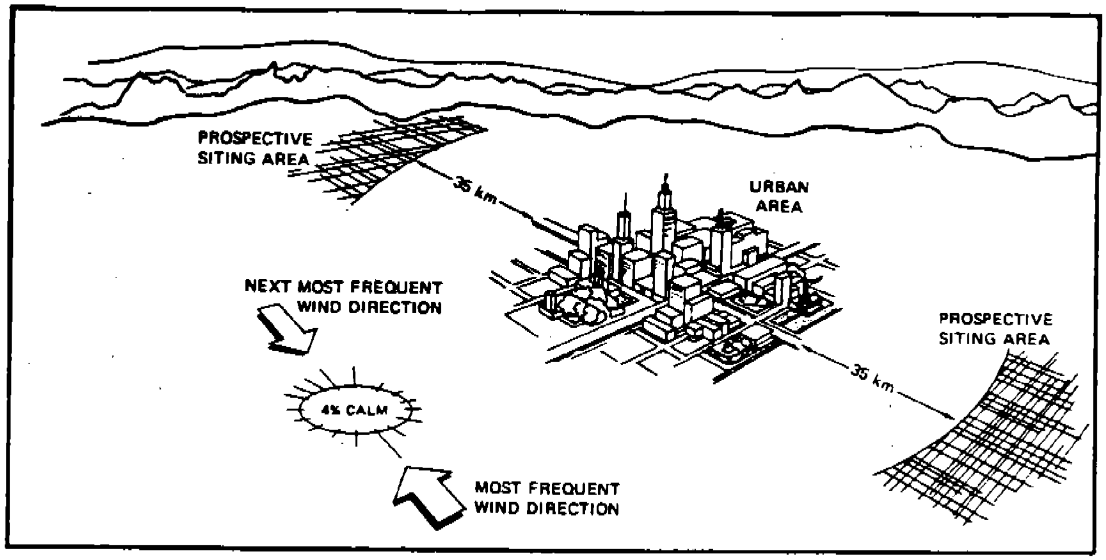
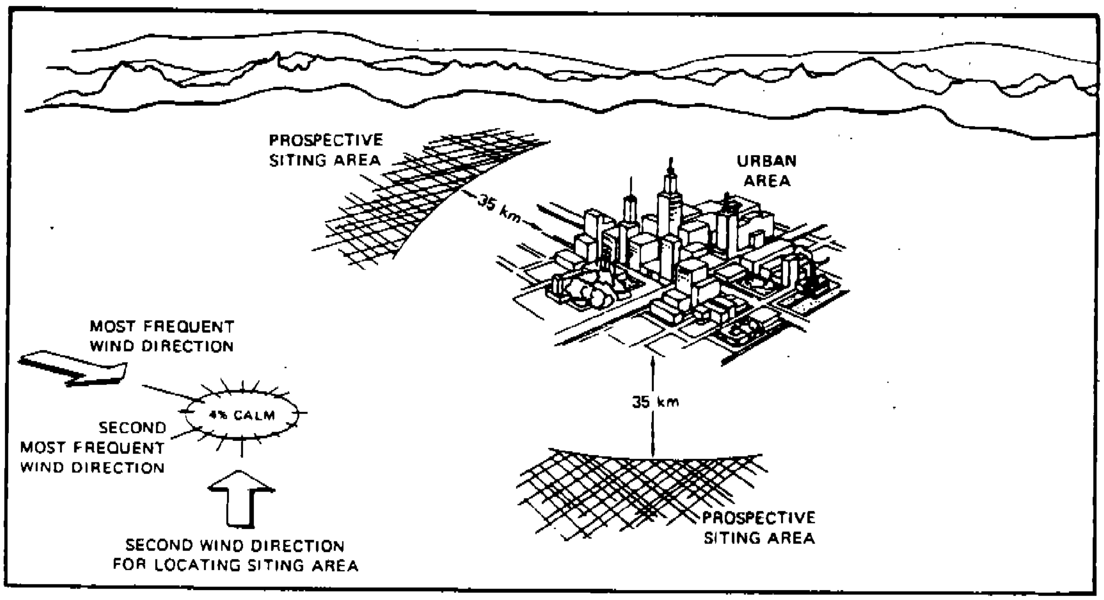


FIGURE 6 SCHEMATIC DIAGRAM OF APPROPRIATE AREAS FOR A REGIONAL MONITORING SITE



(a)



(b)

SA-3515-8

FIGURE 7 SCHEMATIC DIAGRAMS OF APPROPRIATE SITING AREAS FOR REGIONAL MONITORS WHEN TWO SITES ARE PLANNED

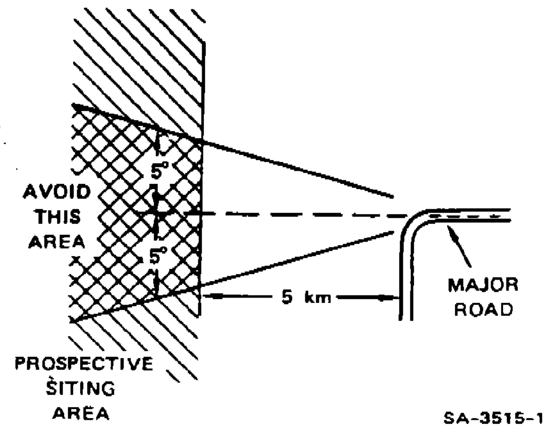


FIGURE 8 SCHEMATIC DIAGRAM ILLUSTRATING THE UNSUITABILITY OF AREAS ALIGNED WITH MAJOR ROADS

In open fields this means 10 m above the ground; in a heavily forested area, the anemometer should be that distance above the general forest canopy.

C. Neighborhood Stations

A schematic diagram of the procedures used to select a neighborhood monitoring station is shown in Figure 10. As with a regional station, the first step of the selection process for neighborhood stations is the acquisition of necessary background materials. Climatological information will be required, especially a joint frequency distribution of winds and atmospheric stability. This is provided by the output of the National Climatic Center's "STAR" program, which is described in more detail in Appendix C.

Aerial photographs and topographic maps will also be useful. Maps that describe the land use more specifically than conventional maps will provide valuable input to the selection process. Often such maps are only available for study in the offices of the planning agency. Finally, maps, or other sources, showing the distribution of traffic on

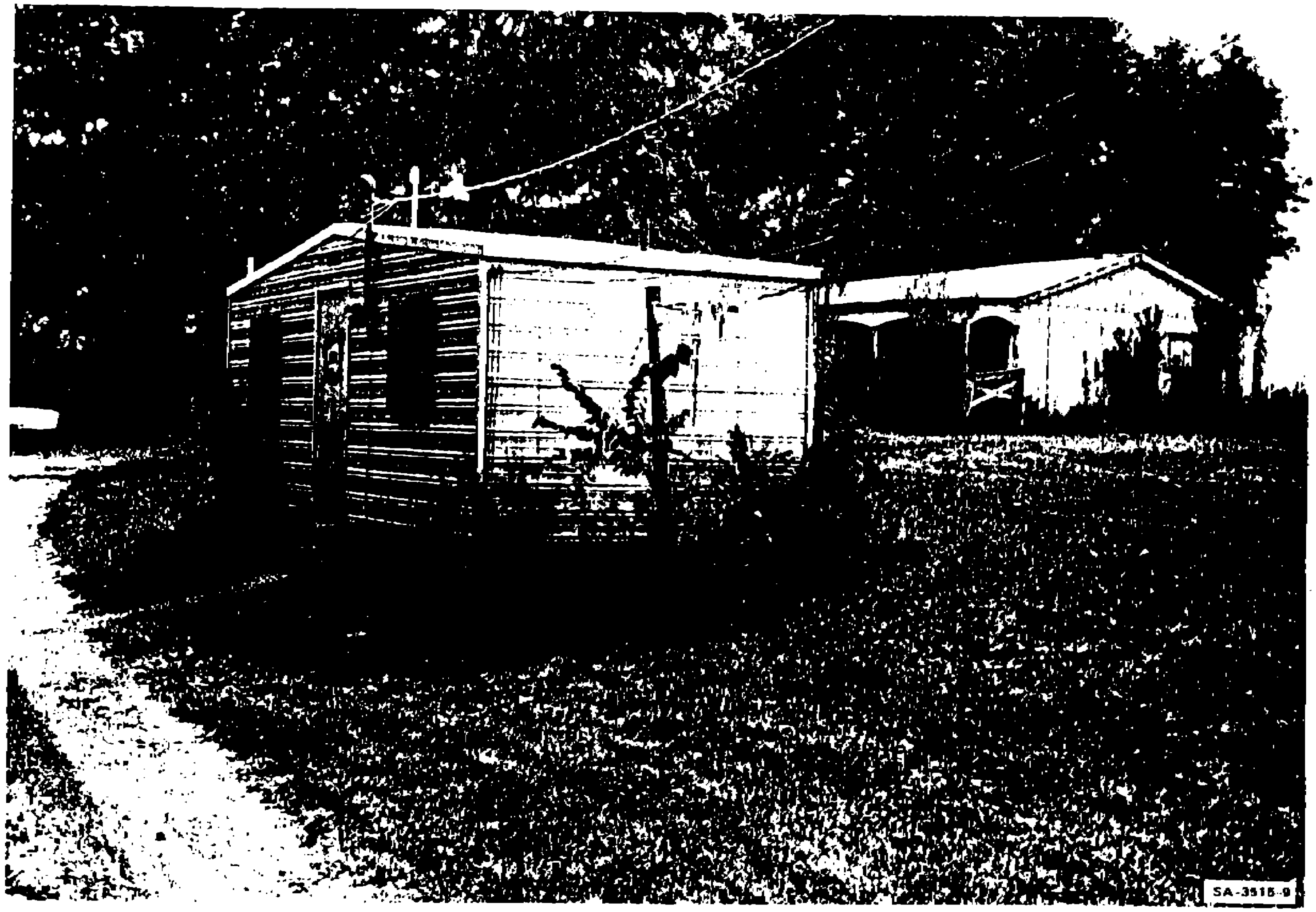


FIGURE 9 EXAMPLE OF A SITE WITH SURROUNDINGS APPROPRIATE TO REGIONAL MONITORING OF CO

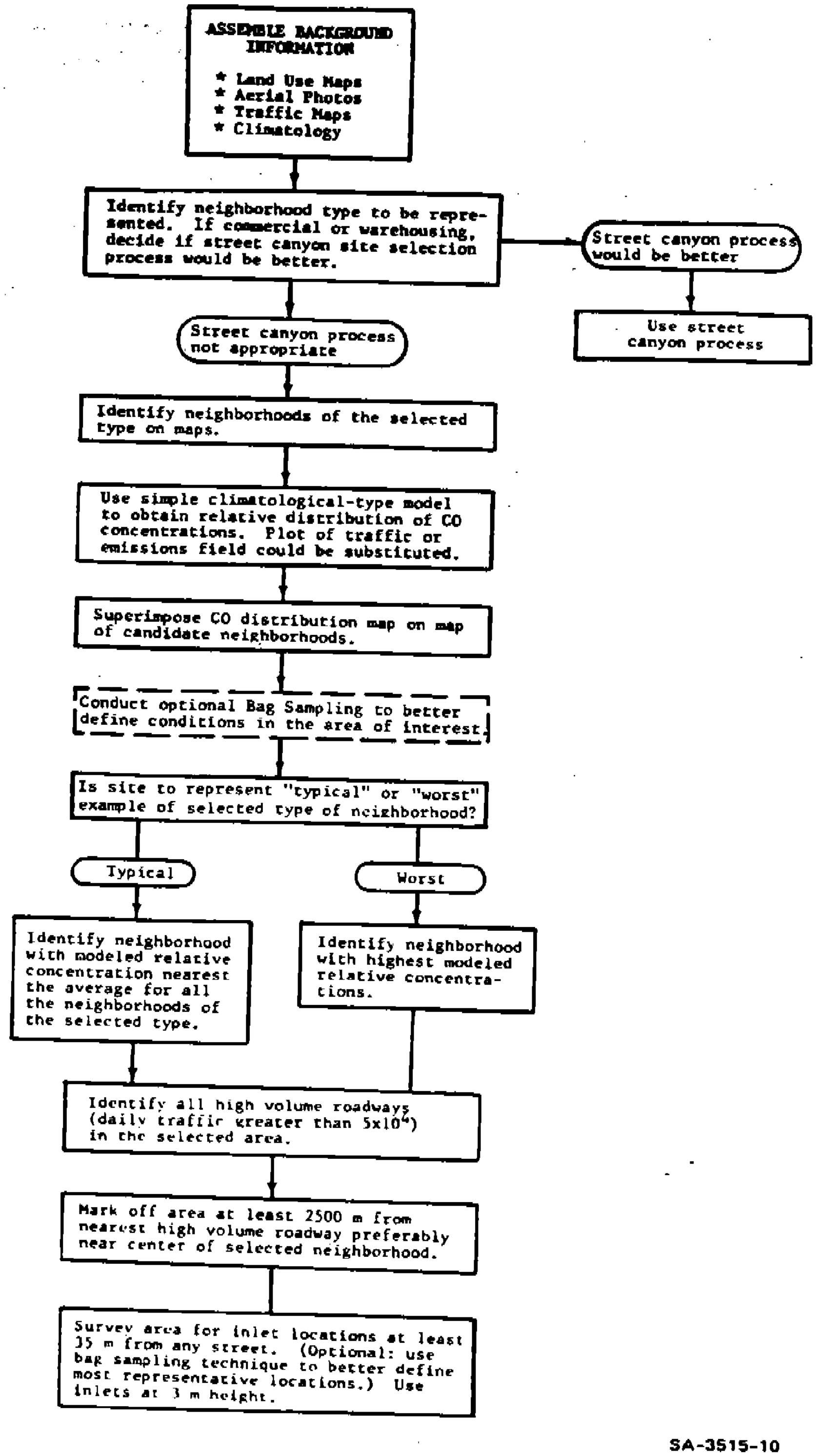


FIGURE 10 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING NEIGHBORHOOD MONITORING STATIONS

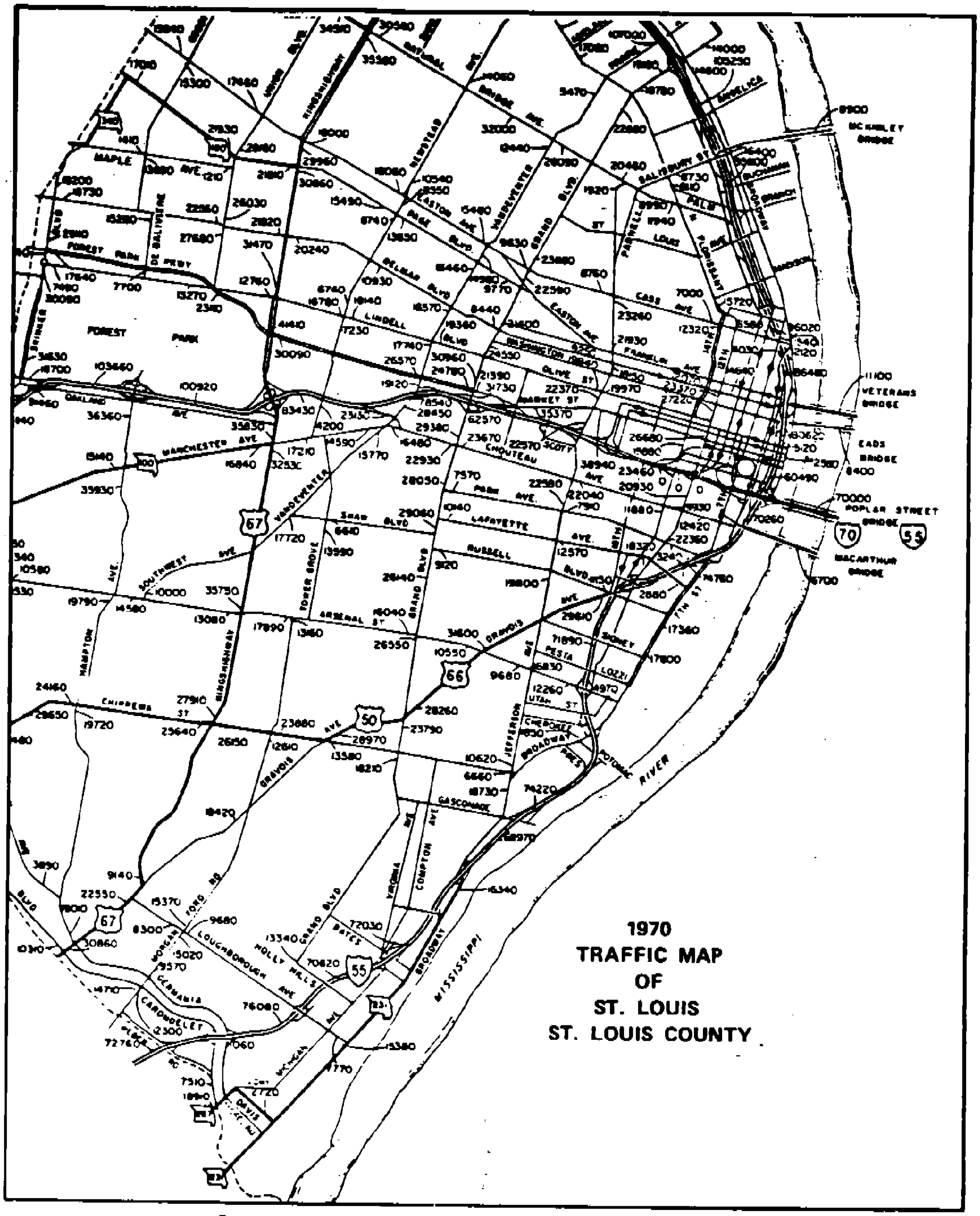
arterials are necessary. An example of this kind of information is shown in Figure 11.

If the type of neighborhood to be represented is characterized by relatively tall, closely spaced buildings—that is, the typical streets, or other open areas between buildings being less than twice the building heights—then the procedures used to locate a middle-scale monitoring station, such as a street canyon site would be more appropriate to the problem than those given below.

After acquiring the necessary background materials, the next step is to use the maps and aerial photographs to identify neighborhoods of the type that are of concern to the particular monitoring objective. Aerial photographs of two different kinds of residential neighborhood are shown in Figure 12. Figure 12(a) shows an area that was built more recently than that shown in Figure 12(b), with its more mature trees and shrubbery. A section of a topographic map corresponding to Figure 12(b) is shown in Figure 13.

After potentially suitable CO monitoring areas have been identified on a map, a simple numerical simulation model can be applied to provide an estimate of average CO concentration over the city. Several suitable models are avaliable, but probably the climatological dispersion model (CDM; Busse and Zimmerman, 1973) would be easiest to apply; its required inputs are the output of the STAR program referred to earlier and an inventory of traffic data converted to CO emission rates in grid squares throughout the city. If computational facilities are not available, then the emissions inventory itself can serve as an approximation to average CO distributions, because of the close relationship between concentration and nearby emissions; see Section IV, D.

If time and resources are available, a program of bag sampling would be highly desirable to provide better data on the relative concentrations in the various candidate neighborhoods. Ott and Mage's (1974) statistics suggest that about 25 samples (24-hour average) at each location would be sufficient. The samples should be collected on random days over a period that will include the annual climatic extremes. When the estimated spatial distribution of average annual concentration—either from modeling or measurements—has been completed, it should be compared with the map showing candidate neighborhoods. If the objective of the monitoring is to obtain data for the particular neighborhood that is likely to have the highest average CO concentrations among all the neighborhoods of the chosen type, the measured or modeled average CO distribution will serve to identify the appropriate area. Similarly, the distribution of average CO concentration can be used to judge which of the candidate neighborhoods is nearest the average for all of them.



NOTE: Figures represent estimated average annual two-way weekday traffic volumes.

SOURCE: Prepared by the Missouri State Highway Department Division of Planning in cooperation with the U.S. Department of Transportation Federal Highway Administration.

TA-8563-128

FIGURE 11 PORTION OF A TYPICAL TRAFFIC MAP

The above discussion represents rather minimal preparatory efforts in the site selection process. Obviously, modeling is subject to considerable uncertainty, which can be reduced by a limited sampling program. Even the limited sampling program only provides estimates of average CO concentration and averages do not allow as complete a comparison among sites as would be desirable. A more extensive sampling program could determine more reliable frequency distributions which would be better bases for comparison.

Once the neighborhoods that most nearly meet the monitoring objectives have been identified, then more specific locations must be selected. These locations must be at least 2,500 m from the nearest highway carrying 50,000 or more vehicles per day. This spacing will limit the contribution of the roadway to less than 1 ppm. Lower traffic volumes will allow for closer spacing. An example of the calculation of a roadway's contribution is presented in Section IV. The inlet must be at least 35 m from any local street having peak traffic of about 800 vehicles per hour. Here again, a limited bag sampling program could be undertaken to define gradients (especially horizontal) in the area. If the gradients are very strong, then a location more distant from the nearest street might be required. Conversely, weak gradients would allow closer placement. The inlet should be at a height of 2.5 to 3.5 m.

Some auxilliary measurements are desirable for a neighborhood station, such as wind. As for the regional sites, the anemometer should be placed about 10 m above the general level of the surroundings; it should be well away from any structures of comparable height. Traffic counts on one or more of the nearby streets would provide valuable supplemental information for interpreting anomalous CO readings.

D. Middle-Scale Stations

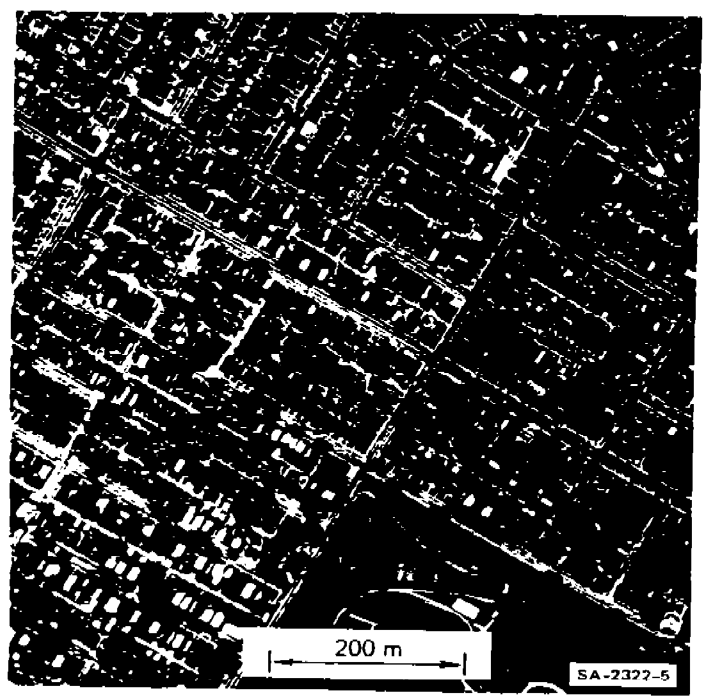
1. General

As noted earlier, this report considers three specific types of monitoring site for measuring middle-scale CO concentrations. These are:

- Street canyon
- Roadway or traffic corridor
- Indirect source.

Only the first two of these are considered in detail because indirect source monitors are most likely to be needed for special studies of limited duration. Thus, this section provides a detailed procedure for selecting a street canyon and traffic corridor monitoring locations, but provides only guidelines for locating monitors that will determine concentrations around the parking areas of indirect sources.

(a) RECENT RESIDENTIAL



(b) OLDER NEIGHBORHOOD WITH MATURE TREES

SOURCE: Dabberdt and Davis, 1972.

FIGURE 12 AERIAL PHOTOGRAPHS OF URBAN RESIDENTIAL NEIGHBORHOODS

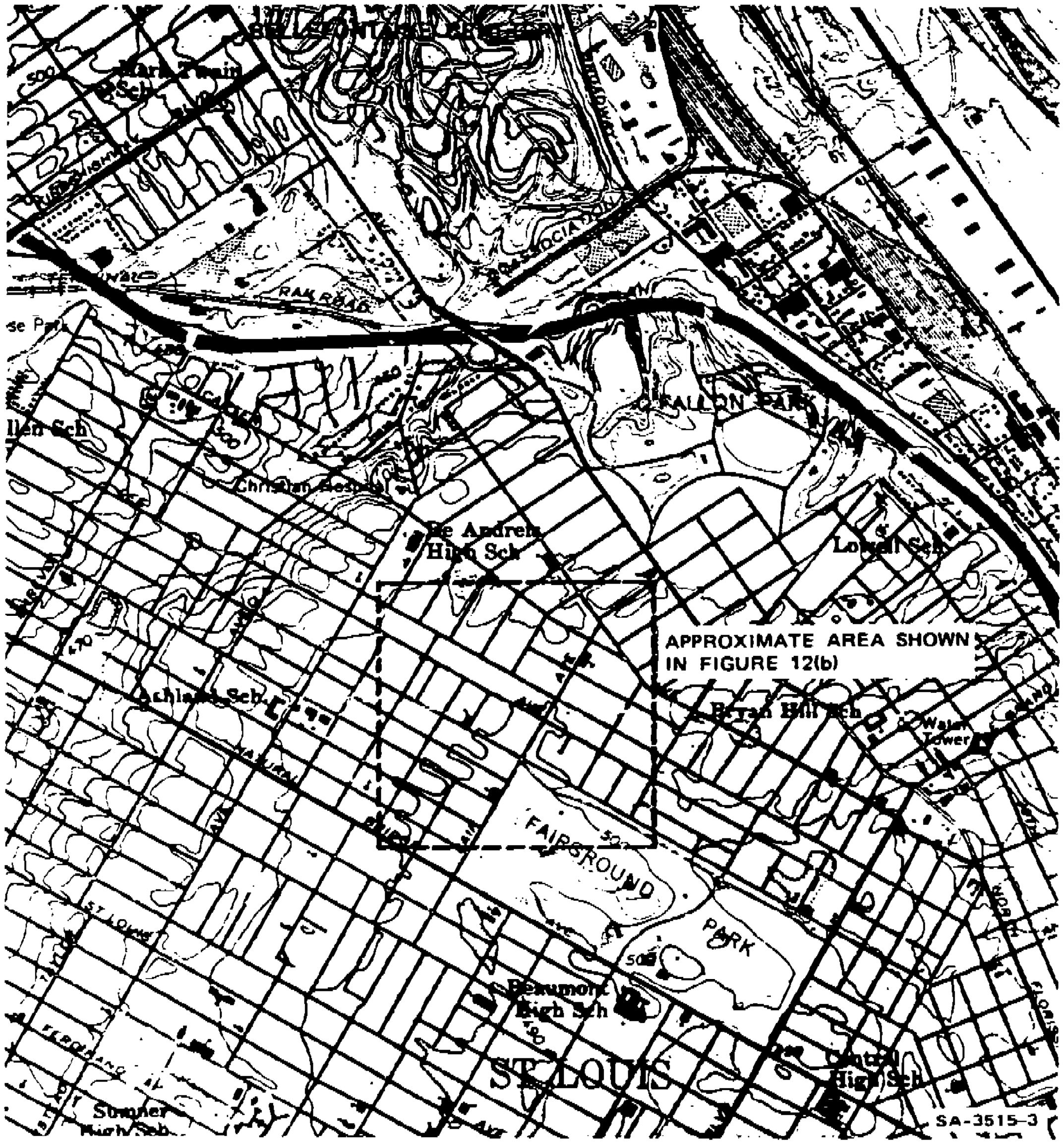


FIGURE 13 A TYPICAL URBAN NEIGHBORHOOD DEPICTED ON A TOPOGRAPHICAL MAP

2. Street Canyon Sites

The first step of the selection process (see Figure 14) is to acquire the necessary background information. This includes the average daily traffic on all the streets in the area, wind roses for different hours of the day, and maps showing one-way streets, street widths, and building heights. These can be obtained from land use maps or by having personnel survey the area and estimate a typical height for each side of each block. Hourly weather observations for a year from a nearby U.S. weather service station will be necessary in some cases.

As indicated in Figure 14, there are two basic monitoring objectives for this type of station. One is to typify the worst conditions to which the public is regularly exposed in the area, and the second is to typify conditions throughout the area.

If the station is to typify the area with highest concentrations, the streets with the greatest daily traffic should be identified. If some of streets are one-way and if local traffic authorities say that they have an asymmetric distribution of daily traffic (i.e., one of the two rush hour periods has much greater traffic volumes than the other), those streets that have their greatest traffic during the afternoon and evening hours should be selected as tentative sites, because the periods of high traffic volume are usually of greatest duration through the evening hours.

When several blocks have been selected as candidates, then the simple computer model described in Appendix A can be applied to each of the tentative locations to determine which is likely to have the highest eight-hour average CO concentrations. If the necessary computational facilities are not available to apply the model, the equations in Appendix A, describing street canyon CO concentration, can be applied, using the most frequent wind direction for the rush-hour period (or periods) of the day. As with the computer model, the object is to determine the block and the side of the street in that block where highest CO concentrations are likely to occur.

If the monitoring site is supposed to typify the entire downtown area, the average daily traffic should be calculated based on all the important street segments in the area. Select those blocks where the daily traffic is nearest the average for the whole area. If possible, avoid street segments that have radically different widths or building heights from those typical of the area.

Attempt to select only two-way streets or one-way streets with similar traffic volumes in the morning and afternoon. If there are no such streets with near-average traffic, attempt to find a pair of

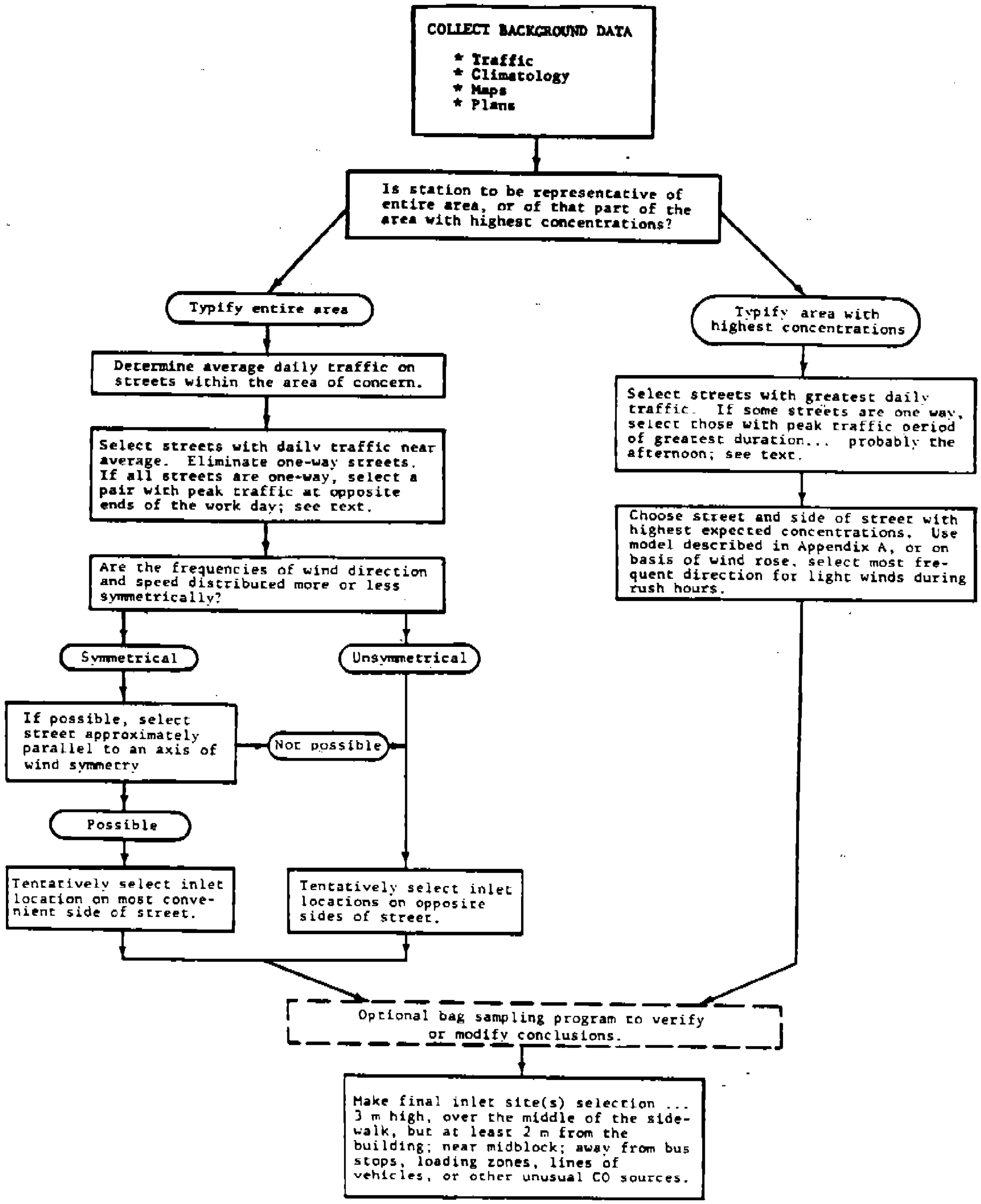


FIGURE 14 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING STREET CANYON STATIONS

streets forming adjacent sides of the same block, as shown in Figure 15 (a), and having near-average traffic. The peak traffic should occur during the morning on one of the two streets and during the afternoon on the other. Figure 15(b) illustrates such a case, with the two streets having peak traffic at opposite ends of the working day.

The next step is to study the frequencies of the various wind directions. If they are distributed with reasonable symmetry about some axis, select a street nearly parallel to that axis. For example, in Figure 5, Salt Lake City, Utah, has a reasonably symmetric wind rose with an axis of symmetry running approproximately north-northwest to south-southeast. North-south streets would be sufficiently parallel to this axis to satisfy the requirement. Most, but not all, of the wind roses in Figure 5 are nearly symmetric; Albuquerque, New Mexico, and Kansas City, Missouri, are examples of asymmetric wind roses.

The Weather Service station for which wind frequencies are available may not always be typical of conditions in the part of the city where the site is to be located, especially in regions with complex topography. Therefore, it will often be wise to seek advice from local meteorologists and make adjustments where necessary.

If data are available showing directional frequencies as function of wind speed, as in Table 3, then the frequencies at the lower wind speeds should be more heavily weighted in the site selection process than those at higher speeds. This is because the lower wind speeds will usually be associated with higher CO concentrations.

If typical concentrations are sought, some consideration must be given to the strong gradients that occur in street canyons. To minimize the effects of these gradients, it is desirable to have a street where the wind blows with equal frequency from the opposite sides of the street, that is the street should be aligned with the axis of symmetry of the wind rose. In such a case, the side of the street on which the inlet is located is of less importance. Another alternative is to use more than one inlet, placing them on opposite sides of the street, or in extreme cases, on more than one street, as shown in Figure 15, to compensate for asymmetries in the daily traffic cycles on one-way streets. If multiple inlets are used, the air flows must be the same through each.

A limited program of bag sampling can be used to check whether the tentatively selected locations are indeed representative of conditions in the downtown area. Such a program could also be used to find other representative locations that were more convenient for one reason or another; for example, space might be more readily available and less expensive, security might be better, and so forth.

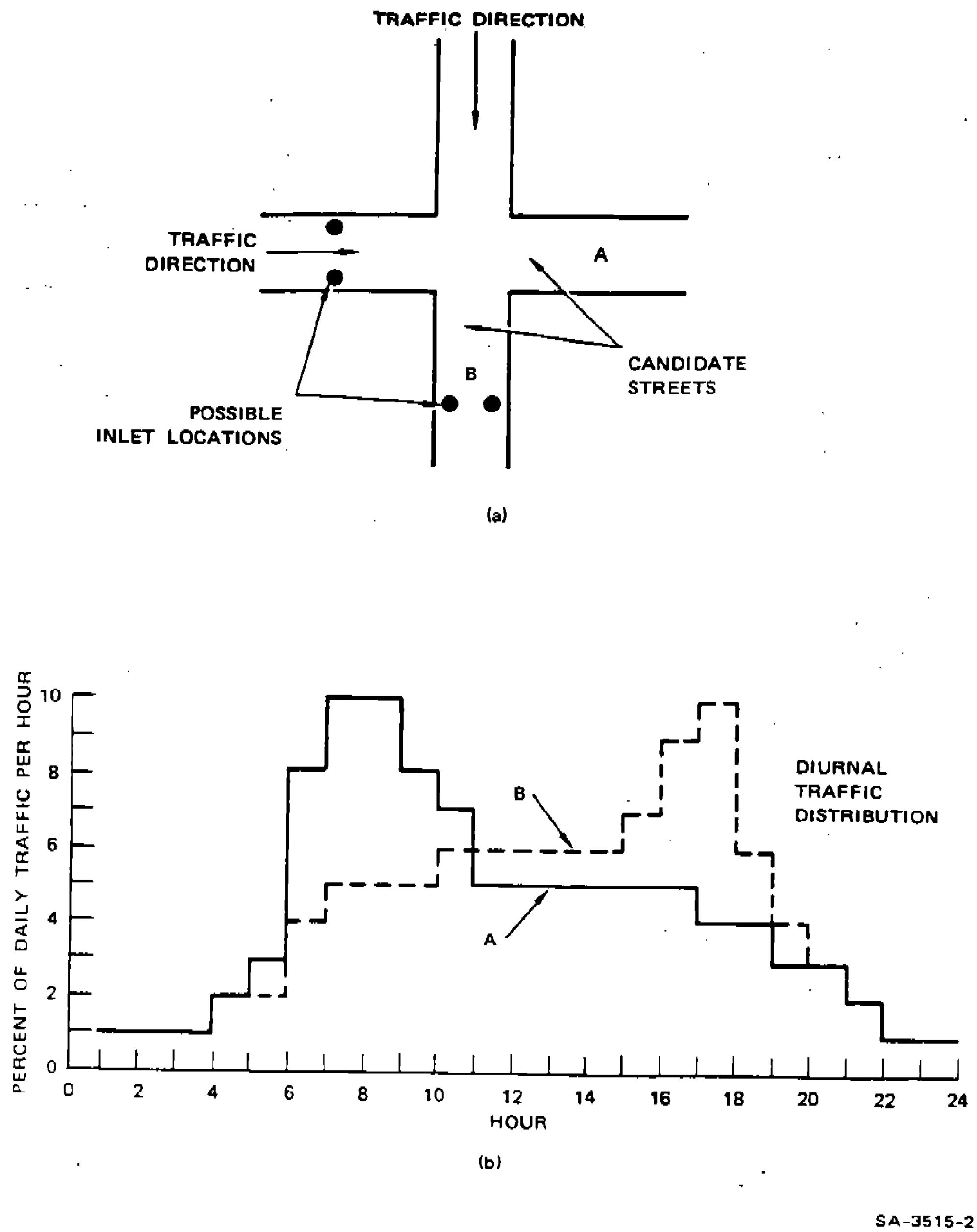


FIGURE 15 EXAMPLE OF A PAIR OF ONE-WAY STREETS WITH PEAK TRAFFIC ON ONE IN THE MORNING, AND IN THE AFTERNOON ON THE OTHER

The actual location of the inlets should be at a height between 2.5 and 3.5 m and over the center of the sidewalk, but not closer than about 2 m to the buildings. The locations should not be closer than 10 m to a cross street to better typify conditions in the larger spaces between intersections. Before finally selecting a location, at least several days should be spent observing activity around that location to make sure that vehicles do not commonly stop and spend extended periods of time idling. Bus stops, loading zones, and areas where lines of cars form regularly should be avoided. Figure 16 illustrates how a downtown street canyon sample inlet might look. The anemometer is shown because this inlet was used as part of a special study in which winds in the canyon were also measured.

A vehicle counter would be a valuable instrument to use in conjunction with the CO monitor. It would provide information that could be used to interpret the records of CO concentration and to identify unusually heavy traffic conditions. Wind measurements in a downtown area are very difficult to obtain without some bias introduced by surrounding buildings; therefore, wind measurements would not have high priority.

3. Roadway or Traffic Corridor Sites

a. Long-term monitors

The site selection procedure for traffic corridor sites is shown schematically in Figure 17. The procedure is very similar to that suggested for selecting street canyon sites. It begins, as should all site selection, with the acquisition of background information, e.g., traffic data, street maps, and climatological information. A decision must also be made whether the purpose of the monitor is to determine the highest carbon monoxide concentrations in the vicinity of roadways, or to monitor more typical conditions. If the purpose is to characterize a high concentration road segment, then the monitor should be located near an area of maximum traffic volume, and on the side of the roadway that is most frequently downwind, especially during periods of light winds.

If the monitor is supposed to characterize concentrations typical of those found near roadways in the area, then average traffic volumes will be sought. The roadway should parallel the axis of symmetry of the wind rose, if possible. (The concept of symmetry of wind roses was discussed in connection with the selection of street canyon sites.) If it does, then the monitor can be placed on either side of the roadway. The basis for selecting one side over the other might be convenience, or greater population exposure.

If it is not possible to locate an appropriately aligned and traveled roadway, then it would be desirable to place inlets in both

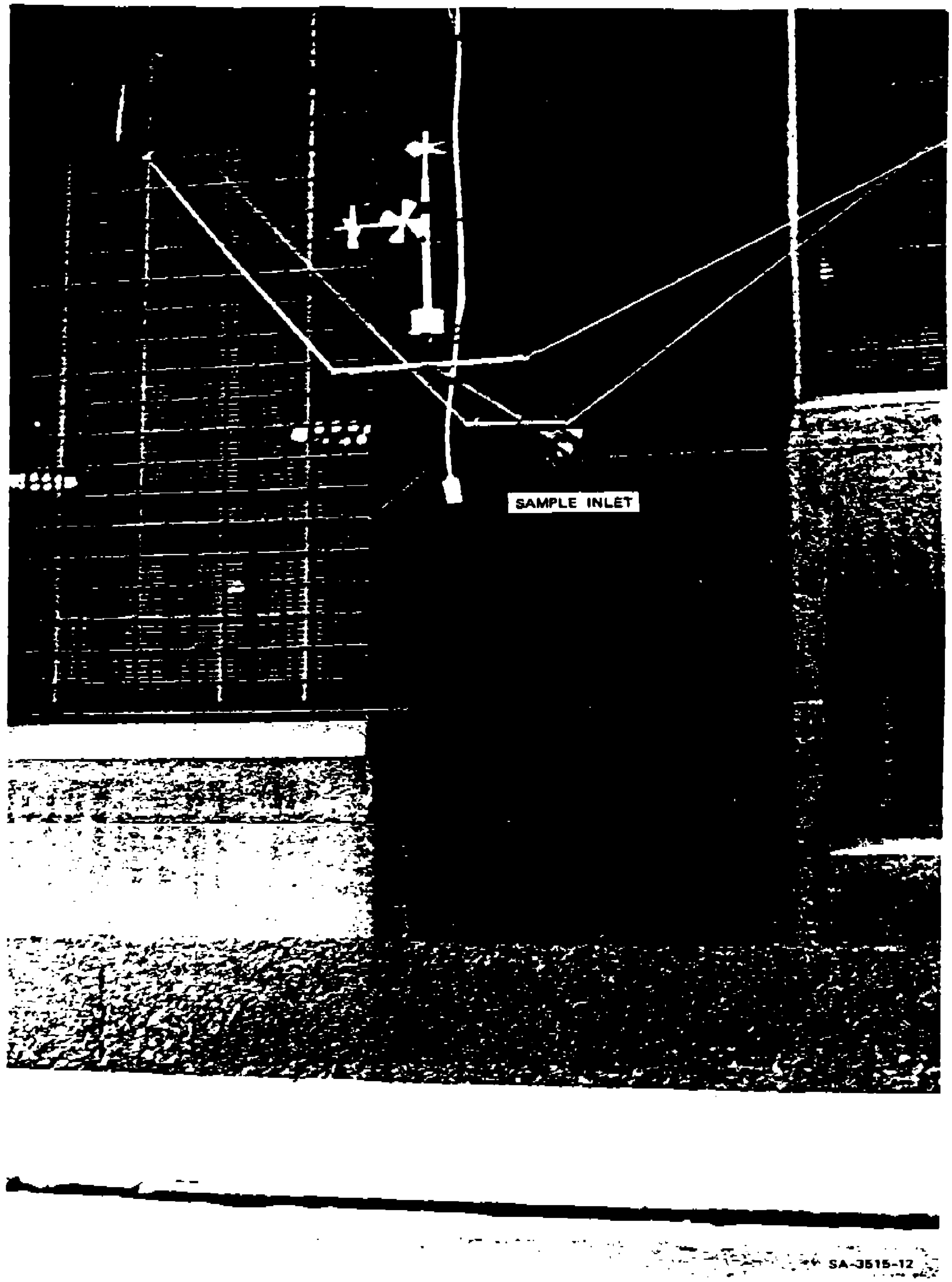


FIGURE 16 SAMPLE INLET IN A DOWNTOWN STREET CANYON

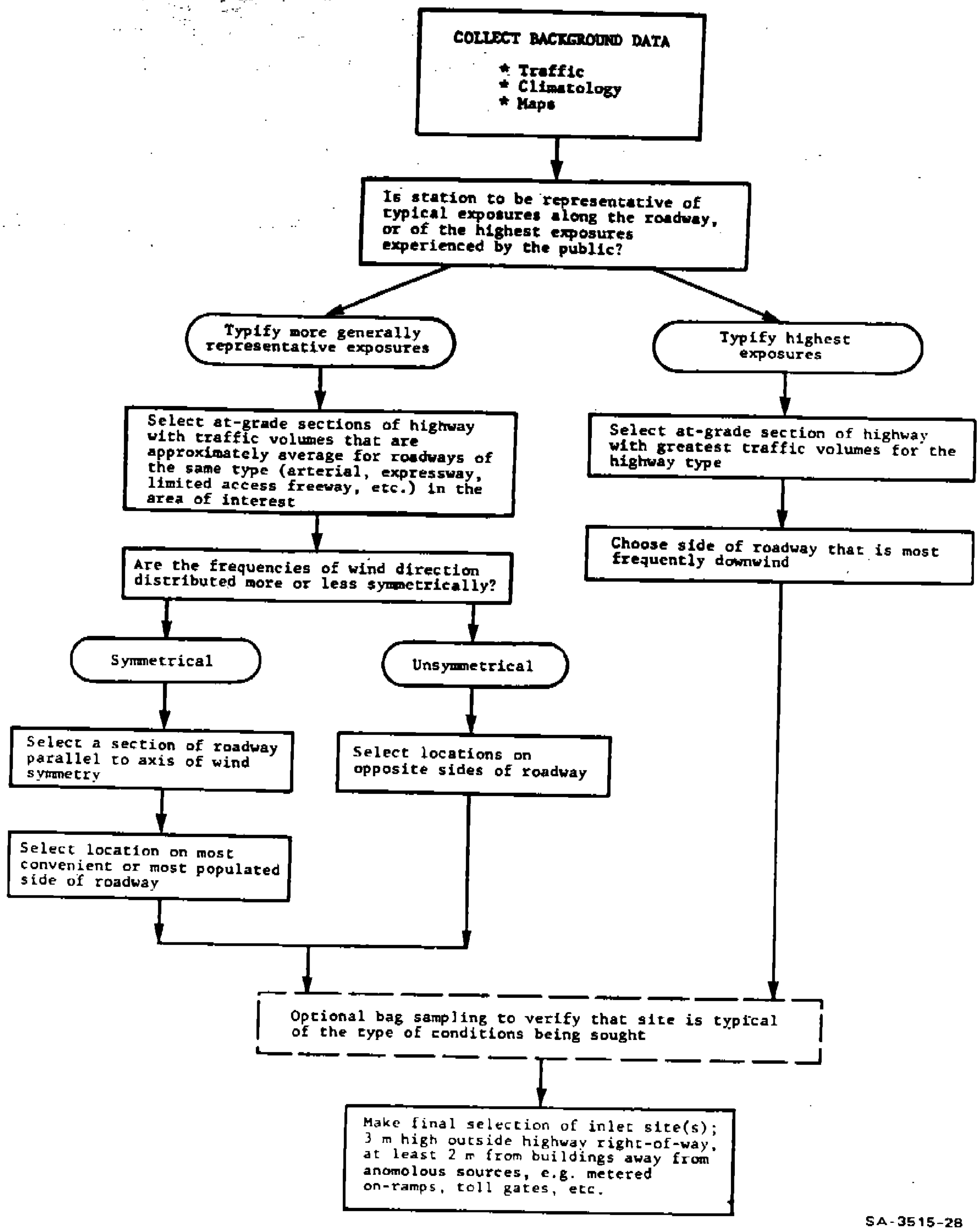


FIGURE 17 SCHEMATIC DIAGRAM OF A PROCEDURE FOR LOCATING TRAFFIC CORRIDOR STATIONS

sides of the roadway to obtain average concentrations. This may be more difficult than for street canyons, but it should be possible to use existing supports for road-signs, or to use utility poles so that the inlet tubing can pass over the highway at a height where it will not obstruct traffic.

To this point, the discussion has dealt only with siting in the vicinity of roadways that are at, or below grade. Elevated roadways present some special problems and their differing heights introduce effects that make site selection for the long-term monitoring of highest concentrations or of typical concentrations nearly impossible. However, special surveys can help to describe CO concentrations in the vicinity of specific sections of elevated roadway and the relationships of these concentrations to meteorological and traffic factors. Siting for such special sites is discussed in the next section. Special, short-term surveys can also provide valuable information for the selection of sites for the long-term monitors.

Once a general location for a monitor has been selected, the inlet should be placed at a height of 2.5 to 3.5 m, outside the right-of-way. If the purpose is to characterize the typical population exposure, then the site should be at a distance from the roadway that is about equal to the average building setback from the roadway. If a worst example is sought, then the monitor should be as near the edge of the right-of-way as possible.

Finally, monitors should not be placed in the vicinity of possibly anomolous source areas. Examples of such anomolous areas include toll gates on turnpikes, metered freeway ramps, and drawbridge approaches. Traffic counters near the monitoring site will provide valuable data for interpreting the observed CO concentrations. An anomometer will also provide valuable corollary information that can be used to determine the extent to which traffic emission might have been carried toward the monitor.

b. Special Surveys

The preparation of environmental impact statements (EIS) for highway projects often requires fairly detailed descriptions of CO concentrations in their vicinity. The California Department of Transportation (formerly the Division of Highways) has developed methods for assessing the air quality impacts of highway projects (Beaton, et al., 1972). These methods are generally quite comprehensive and the documents should be consulted for solutions to monitoring problems of this sort.

In general, the effects of highways at or below grade are most pronounced within about 100 m of the edge of the highway. Measurements made within this distance will usually suffice to define the important impacts. Bag sampling is efficient because it allows samples to be collected at several points while requiring only one CO analyzer. Figure 18 shows an elaborate array of bag samplers used to measure the emission, transport, and diffusion of CO in the vicinity of a divided highway (Dabberdt, 1975). Each of the barrel-like containers shown in the figure holds several bags, which are sequentially filled. In this experiment, CO concentrations and winds were measured at several elevations in the immediate vicinity of the road.

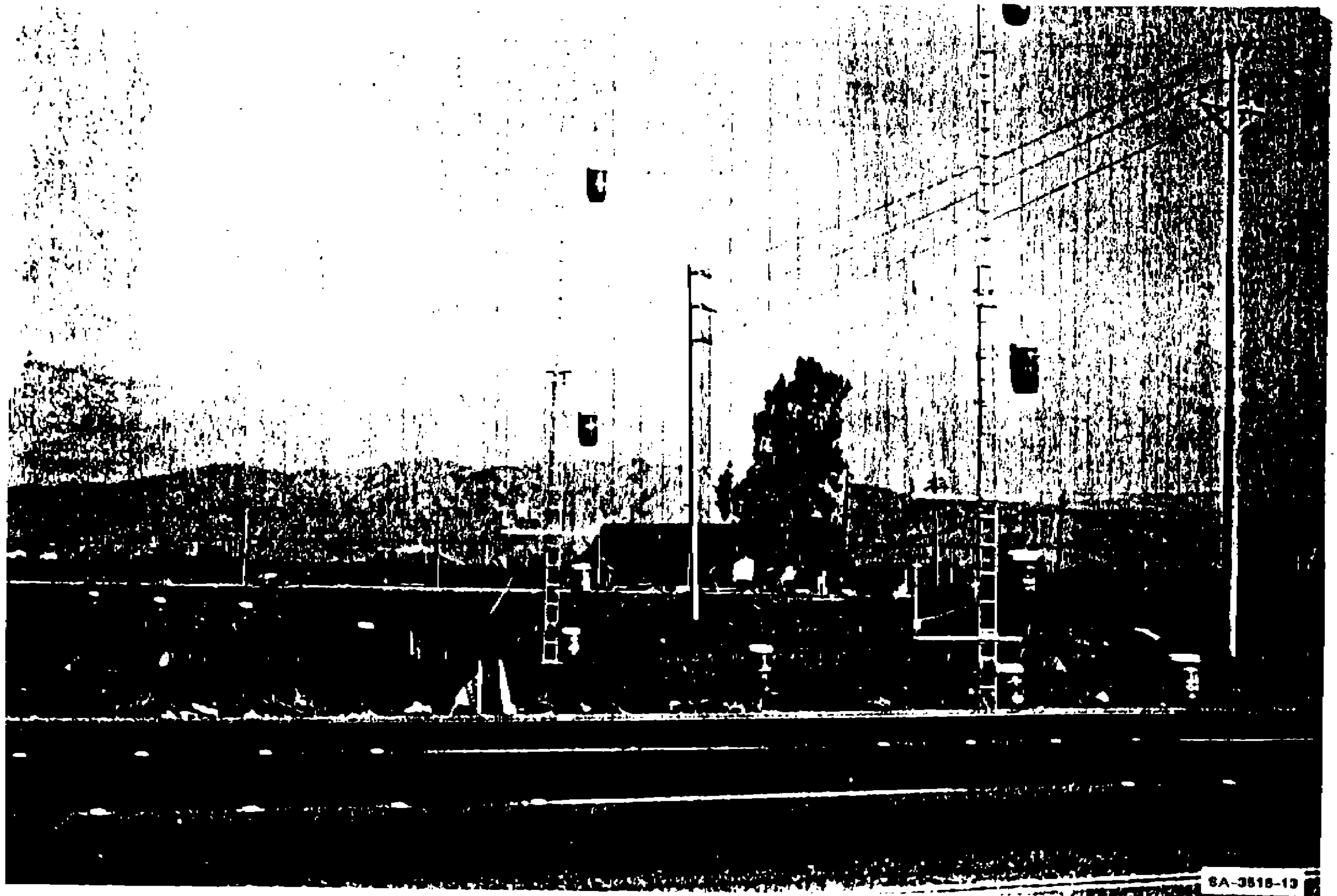
Bags filled over a period of an hour would provide samples compatible with the short-term air quality standard. Of course, most of the samples should be collected on the downwind side of the highway, but at least one sample should be collected upwind of it. Several samples should be taken on each side of the road when winds are nearly parallel to it. Inlets should normally be 2.5 to 3.5 m above ground unless the special, three-dimensional characteristics of the diffusion processes are being studied.

For elevated roadways, samples should be collected in the vicinity of the maximum concentrations that are likely to occur. The expected locations of the maximum values can be most easily estimated from graphs, based on numerical modeling, prepared by the California Division of Highways (Beaton et al., 1972e). An example of one of these graphs is given in Figure 19. The sampling network would be arranged to correspond to the atmospheric stability and wind prevailing during any given test.

4. Indirect Source Sites

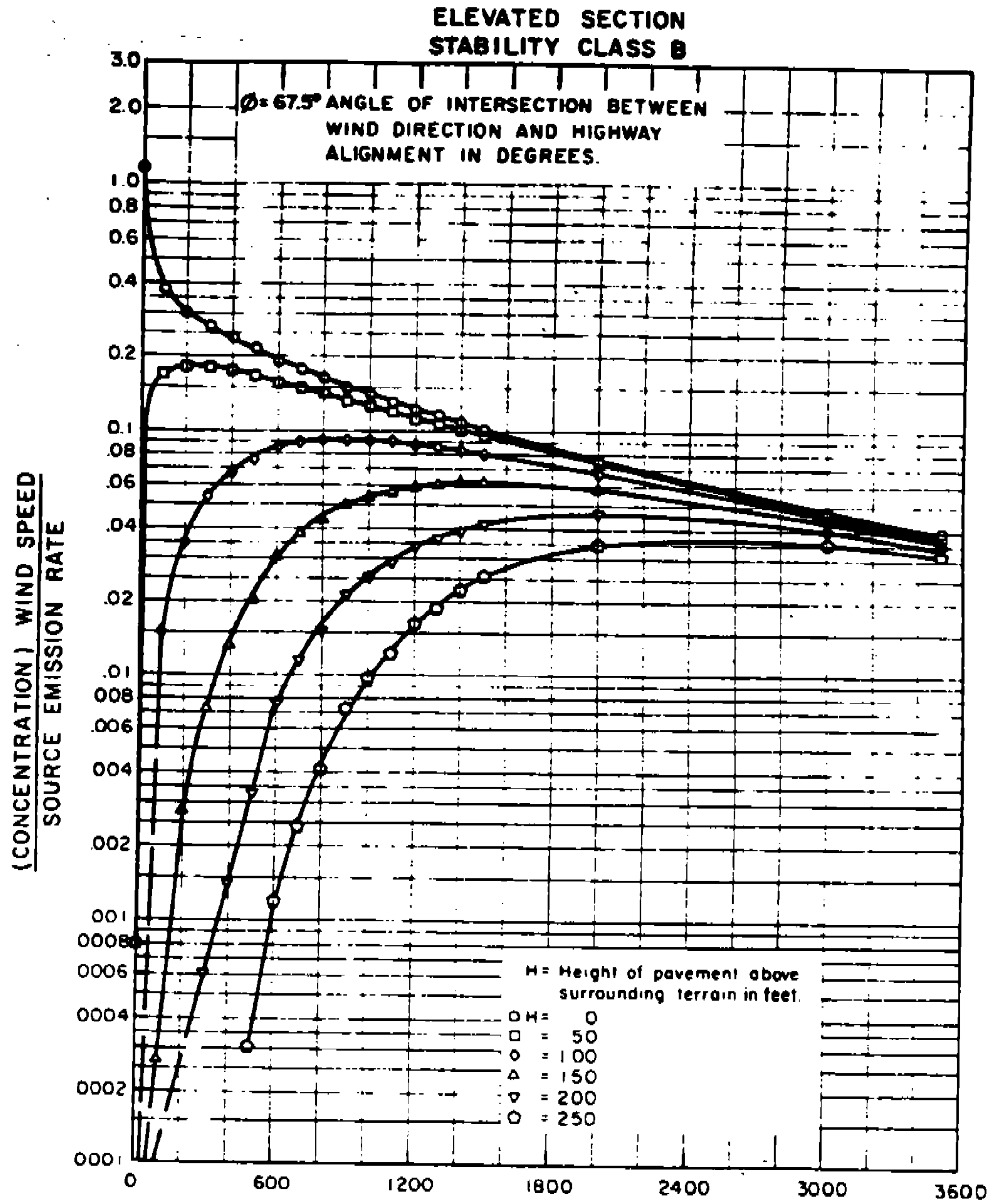
The monitoring of CO concentrations in the vicinity of an indirect source will most often be for a special purpose and of limited duration. To establish prevailing conditions before the indirect source is built, a site of the neighborhood or regional type would be required and the siting requirements would be the same as for any other sites of those types.

To determine the CO levels at an existing indirect source, a combined program of modeling and sampling would be desirable. The modeling would provide information on the areas where the greatest concentrations and the most typical concentrations are to be expected. Models have been developed to describe CO concentrations around indirect sources. (See, for example, Sandys et al., 1975; Patterson and Record, 1974.) A bag sampling program would provide similar information from measurements of the actual concentration distributions that occur in the indirect source region. Such information would be required if a more permanent monitor was planned. Patterson and Record's (1975) measurement program around a Chicago shopping center will provide the reader with some insight about what is required to define CO concentrations around an indirect source.



SOURCE: Dabberdt, 1976.

FIGURE 18 AN EXAMPLE OF A BAG SAMPLING ARRAY NEAR A HIGHWAY



SOURCE: Beaton et al., 1972.

SA-3515-14

FIGURE 19 AN EXAMPLE OF THE DISTRIBUTION OF NORMALIZED CO CONCENTRATION DOWNWIND OF ELEVATED ROADWAYS

As is true for the selection of sites for other kinds of monitors, a decision must be made whether to monitor the highest CO concentrations or to monitor concentrations that are more nearly representative. Once that decision is made, the modeling and bag sampling results can be used as a basis for selecting specific sites. The procedures will be similar to those described for other kinds of sites. If a representative measurement is desired, the use of multiple inlets should be considered seriously. An inlet height of 2.5 to 3.5 m is recommended.

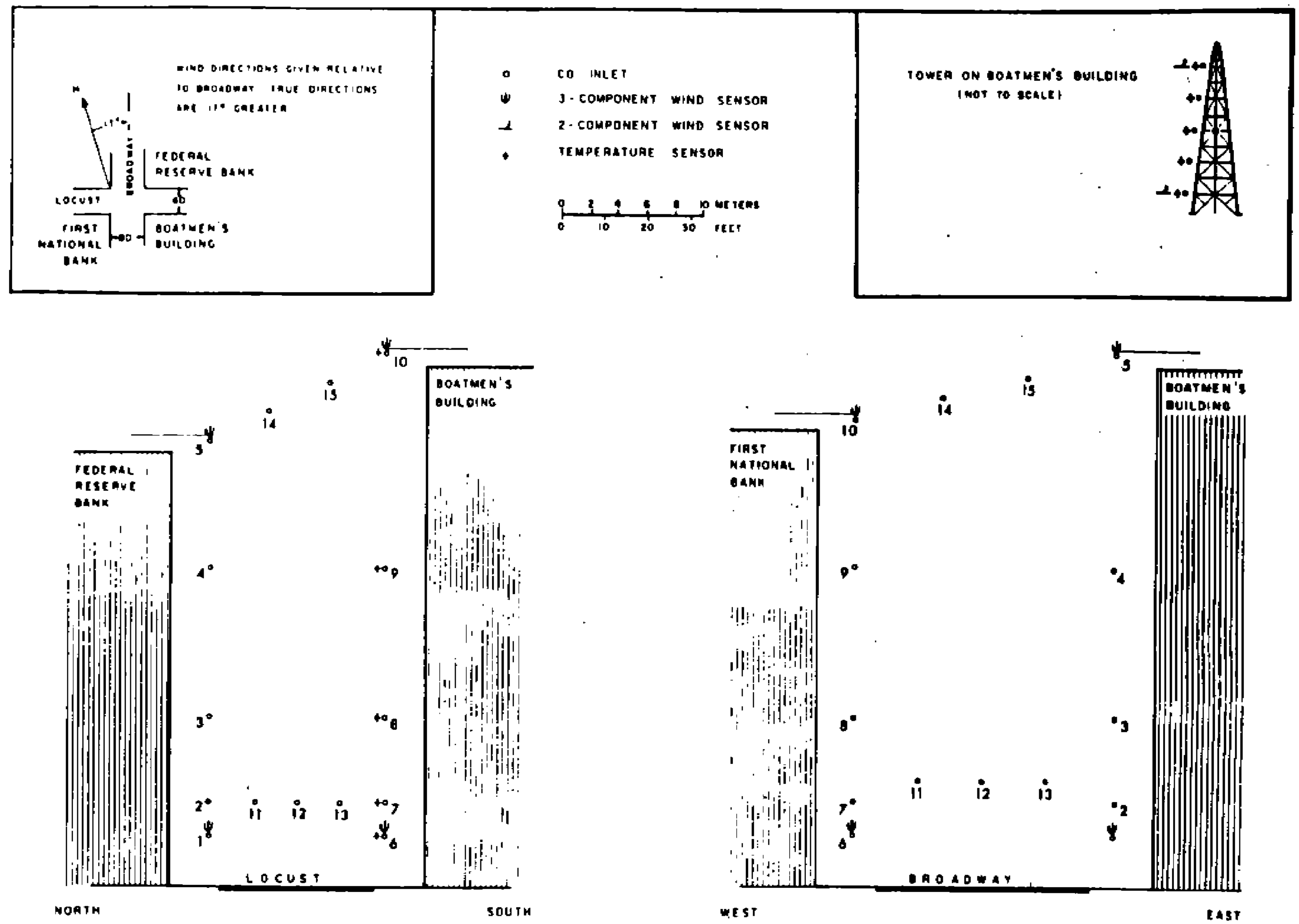
E. Other Types of Stations

The preceding sections have dealt with the location of stations to monitor CO on the regional-, neighborhood-, and middle-scales. Micro-, urban-, national-, and global-scale measurements were not discussed. The following sections present brief discussions of these other scales and some of the factors that bear on the representation of their CO concentrations.

1. Microscale

Every experiment that requires microscale measurements is likely to differ from every other such experiment, and so it is not possible to establish a single set of criteria for this kind of measurement. However, there are some areas of commonality. Microscale measurements are often made in connection with the study of some particular physical phenomenon. The phenomenon will often have definable dimensions and the measurements must be made at locations spaced closely enough to define its significant features. Perhaps, the best way of understanding this is through the use of specific examples.

If one is concerned with the behavior of CO emissions within a street canyon, it is easy to define the overall dimensions of that problem, because the canyon is confined by the street and the buildings on either side of the street. Measurements must be made at enough points within these bounds to define the processes that are taking place. Figure 20 shows one array of inlets that has been used to study street canyon processes. This array was established to determine the transport in the street canyon of CO emitted at ground level. It was hypothesized that during times when winds blew across the street, relatively clean air flowed down one side, across the street (becoming more contaminiated by the emissions), and then up the other side of the street canyon. Since the evidence indicated that there was a helical circulation around the street canyon, the inlets were placed around the edges to the extent possible—obviously inlets cannot be placed at street level where there is traffic, so they were located as low as feasible.



SOURCE: Ludwig and Dabberdt, 1972.

TB-8563-119

FIGURE 20 DIAGRAM OF SENSOR AND AIR INLET LOCATION FOR AN EXPERIMENT TO STUDY DISTRIBUTIONS OF CO IN STREET CANYONS

Figure 21 illustrates another array of microscale samplers. In this instance, the objective was to study the behavior of pollutants in the vicinity of a major divided highway. A photograph of part of this array is shown in Figure 18. The initial rapid mixing that is caused by vehicular turbulence was of particular interest. An estimate had to be made concerning the volume that might be expected to be affected by such turbulent mixing. The array shown in Figure 21 is a reflection of that estimate; the several towers defined the expected vertical and horizontal extent. The placement of the towers and the samplers is the final compromise achieved by the experimenter between the desire to measure at as many places as possible and the limitations imposed by traffic and experimental resources.

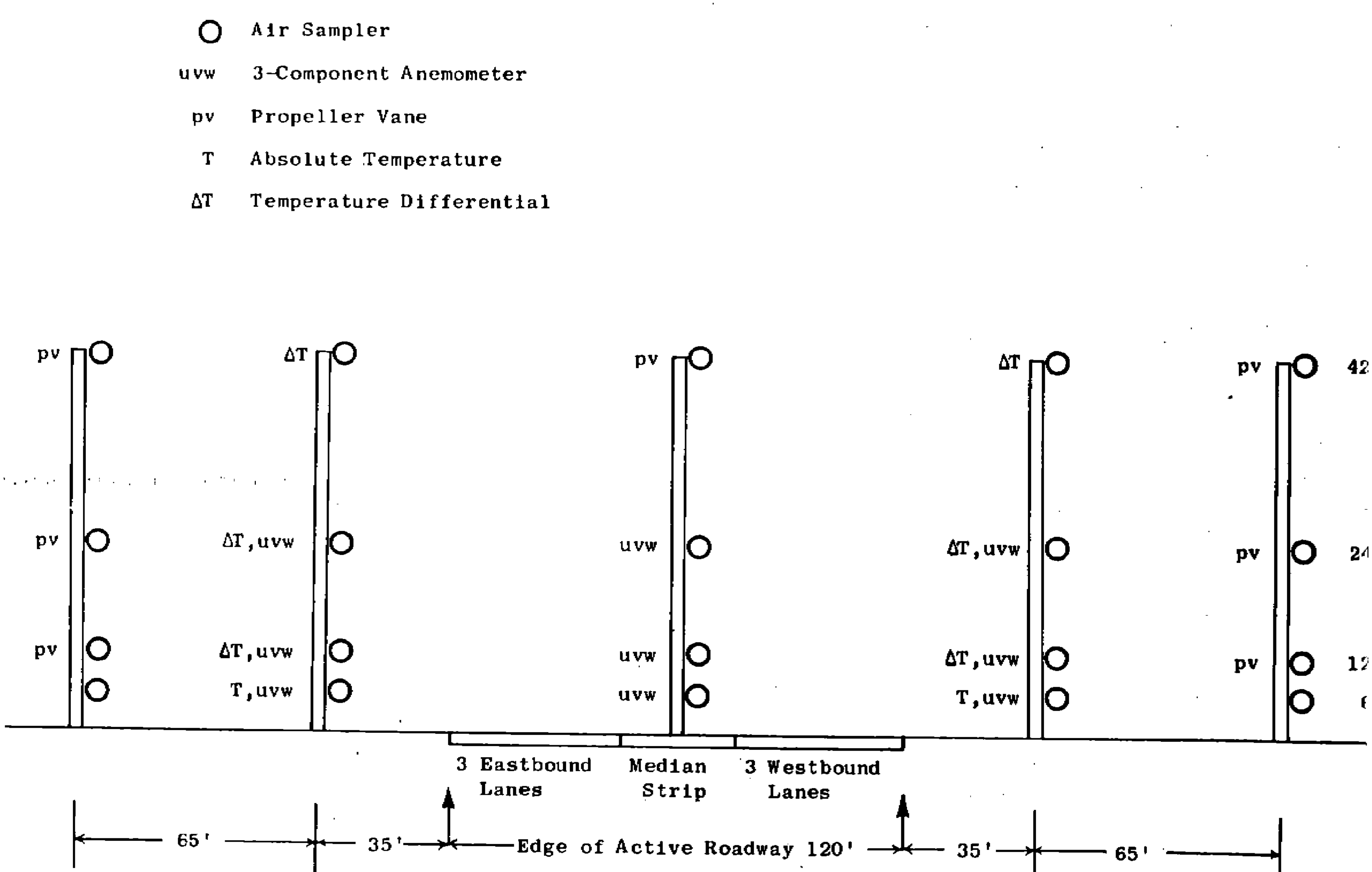
The two examples given above illustrate the importance of defining the scale to be studied through microscale measurements. In the above cases, the total area was rather small. If the distributions of CO in a large parking lot were to be studied, the dimension of interest would expand to those of the parking lot and the measurements would probably be spaced at intervals comparable to the zones into which most parking lots are divided.

Note that microscale measurement programs will generally require a considerable number of corollary measurements to provide all the information required for proper interpretation of the CO concentrations. In the examples discussed earlier, this corollary information included winds and turbulence, traffic, and vertical temperature profiles. The physical relationships that are studied will define the required parameters for any particular case.

2. Urban and National Scales

It is probable that there will be no single site in a large urban area that will represent conditions throughout the city. The obvious approach to this problem is to combine measurements from a number of individual stations through simple averaging, but this can provide misleading results. Better results could be achieved through weighted averaging of the individual measurements, with the methods used for this weighting determined by the objectives that are to be met by the derived measure of urban CO concentration. Although a weighted average might not be appropriate to the purpose of determining compliance with air quality standards, it could be quite useful for comparing CO concentrations in cities of different types.

To define an average CO concentration over the area, each individual measurement would be weighted according to the total area it represents. For instance, measurements from a neighborhood site would be weighted proportionally to the area of the neighborhood(s) that it represents. Similarly, if health effects are important, the weighting of measurements from a given station might be based on the population exposed to concentrations like those represented by that station.



SOURCE: Dabberdt, 1975.

SA-3615-

FIGURE 21 DIAGRAM OF SENSOR AND AIR INLET LOCATION FOR AN EXPERIMENT TO STUDY DIFFUSION NEAR A HIGHWAY

Hence, a downtown street canyon site would be weighted according to the number of people on the downtown streets at the time of the measurement; data from neighborhood sites would be weighted by the numbers of people living in the neighborhood.

The above examples have been presented to illustrate factors that might be important in defining an "urban scale" CO concentration. The importance of objectives had already been emphasized in connection with the selection of individual sampling sites. The examples given above indicate that the objectives are also important in the interpretation of the data and in the synthesis of measures of total urban area CO concentration.

Similar arguments can be applied to measures of national levels of CO as were just applied to the urban scale. The synthesis of a national measure from regional and urban measures could be accomplished through weighted averaging, with the weighting methods dependent on the objectives.

3. Global Scale

To a large extent, the atmosphere itself will accomplish the averaging that is necessary for assessing global scale CO concentrations. If the station is sufficiently remote, the contributions of sources and sinks will be "averaged" by thorough mixing in the air. This report does not address the definition of "sufficiently remote" as it applies to global sites. Note, however, that the site should probably be remote from sinks as well as from sources, the problem being complicated by a lack of understanding and identification of the sinks for CO in the atmosphere.

IV RATIONALE FOR SITE SELECTION CRITERIA

A. Background

The site selection procedures contain some very specific recommendations concerning such things as spacing between monitors and sources or the heights of inlets. The recommendations have been derived through a variety of methods. In most cases, an a priori judgment is required during some phase of the process. The objective of this work has been to make those a priori judgments as recognizable and consistent as possible. This section presents the reasoning and judgments that were used to arrive at the recommendations.

In some cases, such as the recommended heights of inlets, the choices are straightforward. The importance of population exposure to CO concentrations demands that the air be sampled at average breathing heights. However, practical factors, like prevention of vandalism and the potential obstruction to pedestrians, require that the air samples be higher—hence, the recommended 3 m which is an admitted a priori compromise between these two requirements. The recommendation of a range of heights about 3 m requires some analysis to translate the specified range of heights to corresponding measures of the representativeness and the spatial variability of CO concentration. In those latter terms, the a priori judgments are much easier.

Similarly, the recommended spacing between sites and specific sources is clearly understandable if it is restated in terms of the expected maximum contributions of the source to the measured CO concentrations at the site. Thus, we have decided on acceptable levels of interference by a specific source and proceeded to find the minimum spacing between the source and the monitoring site where that level is not likely to be exceeded.

Some of the procedures require other kinds of justification. For instance, potential street canyon sites are identified on the basis of traffic on the streets in the area. The recommended procedure tacitly uses traffic volumes as a surrogate for CO emissions and CO concentrations.

By spelling out the reasoning and the assumptions behind the choices that have been made, it should help others to make rational decisions in cases where their requirements are not met by the recommendations of this report.

Finally, a word about the organization of the following material; it does not parallel the organization of the preceding section.

Instead, it is divided according to the important questions that must be answered for every station: inlet height, distance from specific sources, and so forth. In general, this allows us to present a specific line of reasoning and then procede to show how that line of reasoning applies to each of the different station types.

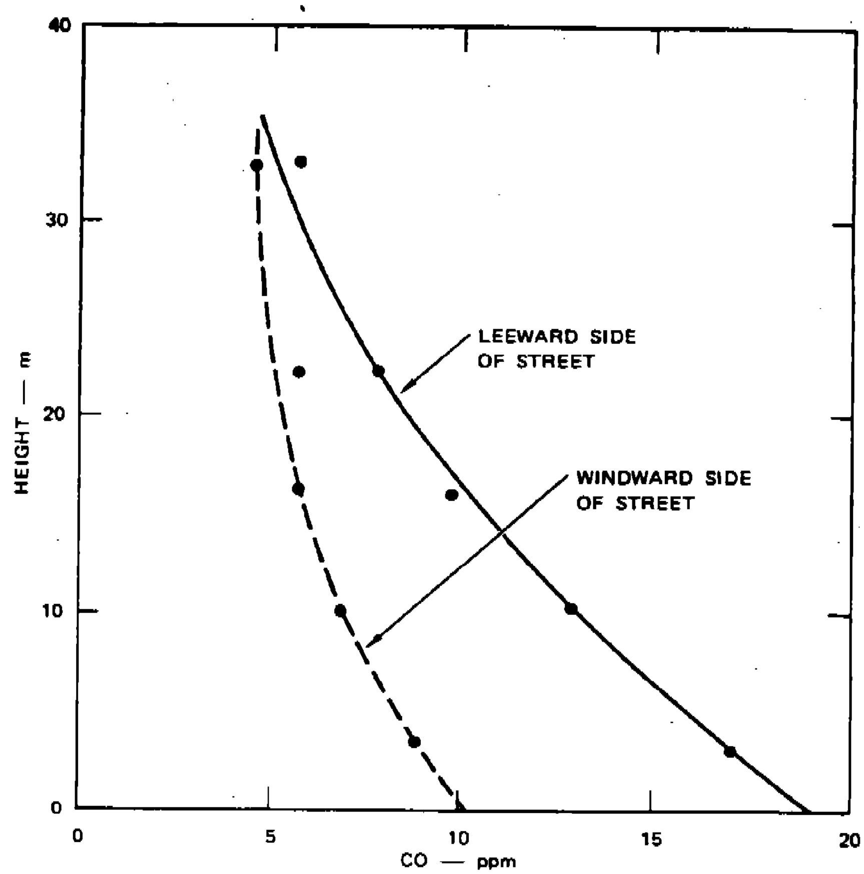
B. Inlet Locations

It was recommended that inlets for most kinds of sampling should be at a height between 2.5 and 3.5 m. The choice of 3 m for the median height has already been explained as as compromise between representation of breathing height and prevention of vandalism.

The recommended 1-m range of heights is also a compromise to some extent. For consistency and comparability, it would be desirable to have all inlets at exactly the same height, but practical considerations will often prevent this. Therefore, some reasonable range must be specified and 1 m should provide adequate leeway to meet most requirements.

The variability of CO concentration with height in a street canyon is sufficiently large that the representativeness of the measurements will be strongly affected by variability of the inlet height. Figure 22 based on observations by Georgii et al (1967) shows vertical gradients of CO concentration from about 0.3 ppm/m to 0.5 ppm/m in the lower levels of a street canyon. Similar gradients are evident in Figure 23 from Ludwig and Dabberdt (1972). The gradients will depend on traffic emissions and on street canyon dimensions, but available observations and the empirical model presented in Appendix A suggest that hour-average vertical gradients of 1 ppm/m are quite possible. A 1 m range of inlet height then corresponds to a range in concentrations of about 1 ppm or less. This seems a reasonable value for measurements in this kind of environment. The reasonableness of the 1 ppm range can be subjectively judged by comparing it to air quality standards—it is about 2 or 3 percent of the one-hour standard and about 10 percent of the eight-hour standard.

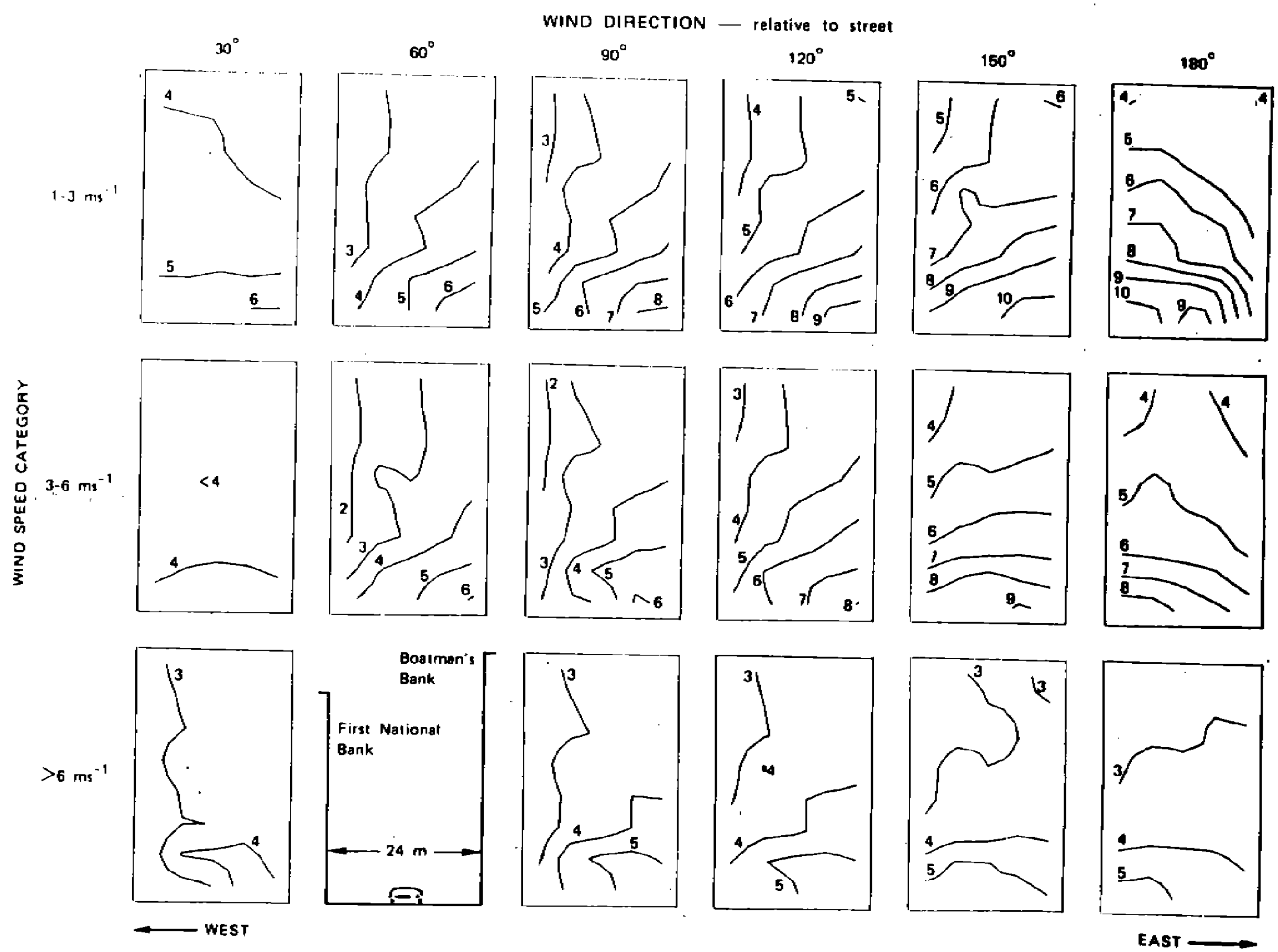
The inlet heights for neighborhood and regional monitoring stations were also specified to be between 2.5 and 3.5 m, although regional monitoring inlets up to 10 m above the surface were specified as acceptable. The objective is to obtain measurements that are consistent with the street canyon type measurements and are taken as near as practical to average breathing heights. As is the case with the street canyon monitors, we would like to minimize differences from the 3 m concentrations. Since most CO is emitted near the surface from line sources (roads and streets), it seems reasonable to use equations for ground-level line sources to evaluate the variability of concentrations



SOURCE: Georgii et al., 1967.

SA-3515-4

FIGURE 22 THE VERTICAL DISTRIBUTION OF CO CONCENTRATION IN A STREET CANYON WITH TRAFFIC VOLUME OF 1500 VEHICLES/HOUR



SOURCE: Ludwig and Dabberdt, 1972.

TA-8563-112a

FIGURE 23 AVERAGE DISTRIBUTION OF CO CONCENTRATION IN A STREET CANYON FOR DIFFERENT WIND CONDITIONS in the vertical. The commonly used Gaussian formulation for such sources is as follows (e.g., see Turner, 1969):

The relative change of concentration, C, with height is given by:

$$\frac{1}{C}\frac{\partial C}{\partial z} = \frac{z}{\sigma_z^2}$$

Where

$$C = \frac{2Q}{\sqrt{2\pi}\, u\sigma_z \sin\varphi} \exp \quad -0.5 \left(\frac{z}{\sigma_z}\right)^2$$

C = concentration (g/m^3)

Q = source strength (g/m s)

u = wind speed (m/s)

σ_z = standard deviation of a Gaussian plume in the vertical, a function of downwind distance, x (m)

φ = angle between wind and line source; validity of equation degrades for $\varphi < 45$ degrees

z = height to instrument inlet (m),

We have specified minimum separations between monitors and line sources, the bases for the recommended separation are discussed later, but for now it is sufficient to note that minimum distances from neighborhood monitors to major roadways should be about 2 to 3 km and to smaller streets about 30 to 40 m. In general, roadway sites will be 15 m or more from the roadway center. At such distances, σ_z will be about 5 m or more in urban areas (see for example, Johnson et al., 1972; Ludwig, et al., 1975); thus, at $z = 3$ m the variation of concentration with height should be about 10 percent/m or less. This is the variability caused by the closest sources; CO from more remote sources will be more uniformly mixed, thus we can be assured that concentration variations associated with a 1 m range of inlet height should be limited to a few percent of the overall concentration.

Minimum separations between regional sites and major line sources should be about 5 km. Rural diffusion proceeds so that σ_z will be about 30 m or greater at these distances (e.g., see Turner, 1969). Over the acceptable range from 3 to 10 m, the variation in observed concentrations should be limited to a few percent, as in the city. Nevertheless, the preferred height is still 3 m, and should be retained as nearly as possible.

It has been recommended that street canyon sensor inlets be located, at least 10 m from the intersection. The choice of midblock locations over intersection locations was made because intersections represent a much smaller portion of downtown space than do the streets between them. The pedestrian exposure times are probably also greater in street canyons than at intersections. Finally, the practical difficulties of positioning inlets are less at midblock locations than at an intersection. Of course, some special studies might want to place the sensor inlet so as to detect the effects of queuing at the intersection, but most purposes will be better served by more representative locations back from the intersection. Some observations made in St. Louis street canyons (Ludwig and Dabberdt, 1972) suggest that there is a reasonable uniformity of CO concentration throughout the part of the block that is more than 10 m from the intersection. This figure has been used as a guide.

C. Minimum Separation Between Monitoring Sites and Sources

In determining minimum separation between a monitoring site and a specific source, the presumption has been that the neighborhood or regional measurements should not be unduly influenced by any one source. A subjective judgment is required as to what constitutes undue influence. There are at least two bases for making that judgment. A maximum concentration value can be assigned and the separation between the monitoring site and all sources should be such that the contribution from any one source does not exceed the assigned maximum. The other approach is to examine the disturbance in the concentration gradients caused by sources and assign a maximum allowable gradient from any given source. Both approaches were tried in connection with roadway sources and are discussed below. In the examples that follow, typical emission rates have been assigned. These are based on typical CO emission values for vehicles during the early- to mid-1970s and on perusal of traffic maps and other documents to obtain reasonable values for average daily traffic.

The line source equation that was presented earlier and served as a basis for estimating vertical variability can also serve as a basis for determining the minimum separations that are required between sources and monitors. Only a very small error is introduced if we assume that the sources and the monitor inlets are at the same height. The equation then simplifies to:

$$C = \frac{2Q}{\sqrt{2\pi}\, u\sigma_z \sin\varphi}$$

As noted before, if a monitoring site is to be representative of a fairly large surrounding area, the contributions from any one source should either be small or the gradients of those contributions should be small. That is, one of the following inequalities should be satisfied:

$$\frac{2Q}{\sqrt{2\pi}\; u\sigma_z \sin\varphi} < C_{max}$$

or

$$\left|\frac{1}{C}\,\frac{\partial C}{\partial (x\sin\varphi)}\right| = \left|\frac{1}{\sigma_z \sin\varphi}\,\frac{\partial C}{\partial x}\right| < G_{max}$$

where G_{max} is the desired maximum of relative gradient of concentration away from the roadway and C_{max} is the maximum allowable contribution to the concentration. Johnson et al. (1971) have suggested that in urban areas σ_z can be related to x by an equation of the following form:

$$\sigma_z = ax^b$$

Thus

$$\frac{\partial \sigma_z}{\partial x} = abx^{(b-1)}$$

and the two inequalities become

$$\frac{2Q}{uax^b \quad 2\pi \sin\varphi} < C_{max} \;; \qquad \frac{b}{x\sin\varphi} < G_{max}$$

At this point, some values must be assigned to the terms so that some reasonable values can be chosen for the minimum distance ($x \sin \varphi$) from the roadway, at which at least one of the criteria can be satisfied. The following values have been chosen as reasonable for major urban roadways:

$$Q = 0.07 \text{ g/m s}$$

Note, that this corresponds to about 10,000 vehicles/hr,* emitting about 40 g/vehicle-mile.

φ = 40 degrees

u = 1 m/s

C_{max} = 0.001 gm/ m³ (approximately 1 ppm)

G_{max} = 0.0002/m (20 percent/km)

---

* Peak hour traffic is usually about 10 percent or less of the total daily traffic; hence, the corresponding total daily traffic is around 100,000 vehicles.

Johnson et al. (1971) have proposed the values of a and b given in Table 4 for use with different atmospheric stabilities in urban areas.

Table 4

VALUES OF CONSTANTS USED TO REPRESENT VERTICAL DISPERSION AS A FUNCTION OF DOWNWIND TRAVEL DISTANCE

Stability Type	Values	
	a	b
Very unstable	0.07	1.28
Unstable	0.12	1.14
Slightly unstable	0.23	0.97
Neutral	0.50	0.77
Slightly stable	1.35	0.51

After making the substitutions, minimum distances between monitoring sites and the hypothesized roadway can be estimated for each atmospheric stability class according to the two different criteria. The results are summarized in Table 5. Since only one criterion (not both) has to be satisfied, it appears that neighborhood monitoring sites more than about 2 to 3 km from major highway sources can be expected to be generally free of undue influence from those sources.

Table 5

MINIMUM DISTANCES (KM) BETWEEN A LARGE ROADWAY AND A NEIGHBORHOOD MONITORING SITE

Stability Class	Gradient Criterion	Concentration Criterion
Very unstable	6	0.3
Unstable	6	0.3
Slightly unstable	5	0.4
Neutral	4	0.81
Slightly stable	2.5	3

For a source strength of 0.007 g/m s, corresponding to a smaller city street with peak traffic about 500 vehicles per hour and emissions of about 80 gm/vehicle-mile, the 1 ppm concentration criterion indicates minimum distances of about 30 to 40 m between the monitor and the source. Of course, it can be argued that the contribution from any individual smaller street ought to be kept at even lower levels than the contributions from the larger thoroughfares if the monitored values are to be representative of the contributions from all sources, large and small. If we specify the maximum acceptable contribution from a source of 0.007 g/m s to be 0.5 mg/m^3, then the minimum allowable separation would be about 100 m from a middle size street source such as that specified. For smaller streets the permissible separation can be less. It is not too difficult to find inlet sites that are 30 or 40 m from the nearest street of any appreciable size, so we have chosen 35 m as the minimum setback from any street for a neighborhood site.

Street canyon and traffic corridor sites are chosen to provide a measure of the influence of the immediate source. For such purposes, no minimum separation distance is required. This is consistent with the smaller scale area to be represented by street canyon or other traffic oriented sites as compared to the scale being represented at a neighborhood site.

At the other extreme, for regional monitoring in rural areas, a very small limiting concentration will be desirable; we have chosen 0.2 mg/m^3, which is comparable to world-wide background concentrations (Robinson and Robbins, 1967). Away from cities, major roadways may carry about 3,000 vehicles/hr at peak times. Speeds will generally be faster than at peak hours in the city, so emission rates of about 15 g/mile would be reasonable. This leads to peak line-source emissions of about 0.008 g/m s. Rural diffusion takes place at somewhat slower rates than in the city. Turner (1969) has given curves defining σ_z in rural areas as a function of x. Using those curves and the above figures for source strengths and concentration limits gives a minimum separation of about 4 or 5 km between the monitor and any large intercity highway.

If the wind blows parallel to an extended straight section of highway, there can be substantial concentrations along the direction of the section, even at substantial distances downwind of the point where the road has turned so that it is no longer parallel to the wind. To avoid exposure to such concentrations, we have recommended that the site not be chosen within about 5 degrees of the extension of the road alignment (see Figure 8). Under stable atmospheric conditions, a Gaussian plume from a point source will have a horizontal width that falls within this subtended angle at distances of more than a few kilometers. In this instance, "width" of the plume is defined as two standard deviations on either side of the center line. If the line source is considered as a series of point sources, then keeping outside the $\pm$ 5 degree angle will generally avoid very strong influences during periods when the wind parallels the roadway.

The above approach does not consider climatological factors. If winds are only infrequently from certain directions, a site could be placed so that it would be influenced only infrequently. However, such an approach might increase chances for subsequent misinterpretation of the data by introducing correlations with wind direction that were not related to general, larger-scale factors.

Our approach to defining the distance that a regional station should be outside of an urban area has been based on reasoning similar to that used above in connection with the determination of minimum separations between neighborhood sites and roadways. That is, an attempt has been made to limit the influence of the city on the nearby regional monitors. We have taken advantage of similar calculations made for other purposes. Figure 24 (from Stanford Research Institute, 1972) shows calculated relative concentrations downwind of a circular area source, 70 km in diameter. Within the area, source emission rates are highest at the center, decreasing in Gaussian fashion to 24 percent of the central value at the edge. The figure illustrates that where the atmosphere is fairly stable, mixing proceeds slowly and ground level concentrations remain high for fairly great distances.

Estimates based on data published by EPA (1973) for Washington, D.C., and on the Los Angeles traffic densities of Roberts et al. (1971) indicate that maximum emission rates, Q_o, of around $1.3 \times 10^{-4} g/m^2 s$ are typical. If we assume the lightest winds to be about 1 m/s and if, as before, we try to limit the effects on regional monitoring to about 0.2 mg/m^3 then, as Figure 24 shows, the regional site should be 35 km or farther outside the city.

D. The Importance of Sources at Various Distances from the Monitor

It is probably evident to the reader that the selection processes that have been recommended emphasize nearby sources, or lack thereof. In selecting a site for typifying some aspect of downtown street canyon CO concentrations, the process is largely limited to finding a typical block, or a worst block. Little attention is given to the interrelationships with all the other sources in the urban area. For neighborhood sites, the area of concern expands. In a "neighborhood" that is reasonably homogeneous (i.e., without individual major sources) the area of concern expands to a few kilometers. The scale expands still further to tens of kilometers for regional sites. The reader can infer from all this that concentrations at a site are highly influenced by sources close to that site. Thus, the monitor readings are expected to be characteristic of the immediate surroundings. This expectation has prompted many of the recommendations that have been made.

The influence of local sources has been shown often. For example, Ott (1971) observed that in San Jose, California, stations more than "several hundred feet" from traffic should read approximately the same CO concentration. Perkins (1973) concluded that a monitoring site in the southwest part of the Los Angeles basin was probably strongly

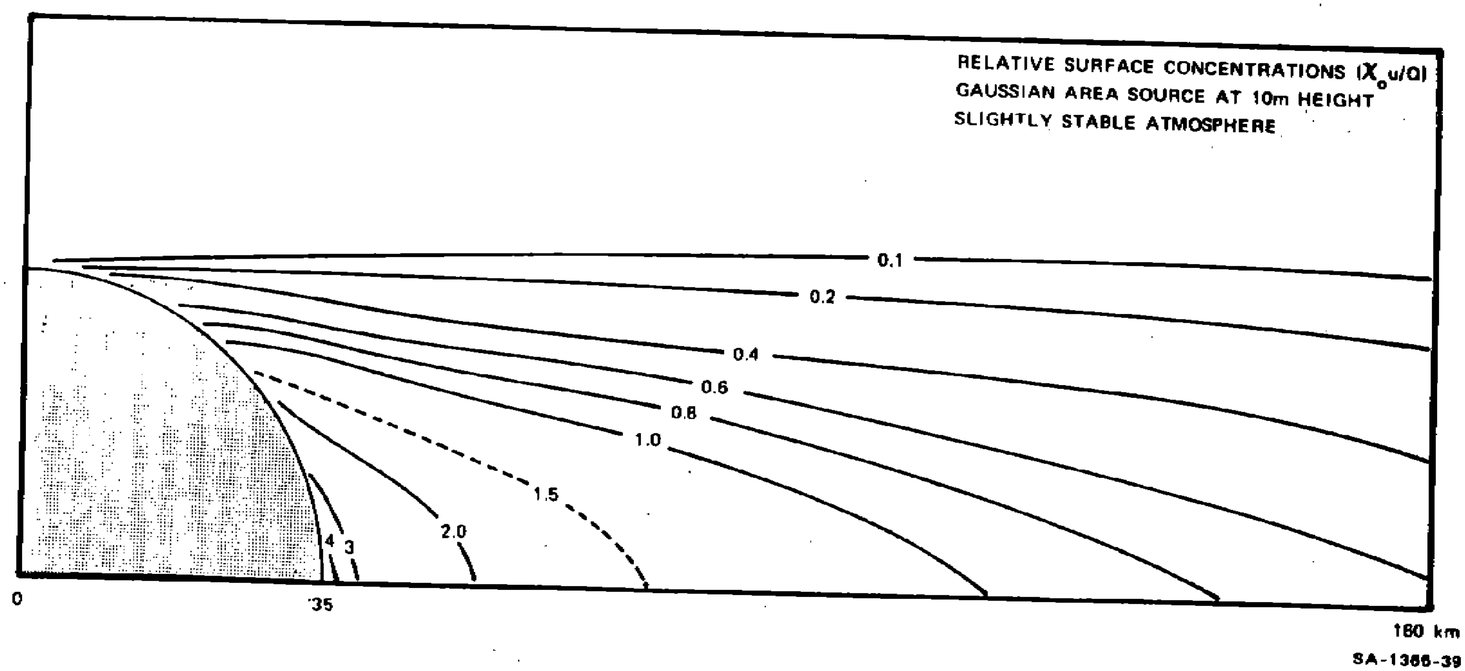


FIGURE 24 NORMALIZED CONCENTRATIONS COMPUTED WITH A GAUSSIAN DISPERSION MODEL

influenced by local traffic. Kinosian and Simeroth (1973) found that the annual, maximum hour-average CO concentration varied strongly with distance from the nearest traffic for nine Los Angeles area monitoring sites; their results are rather startling, as shown in Figure 25. This figure is based on the average of the maxima for two different years.

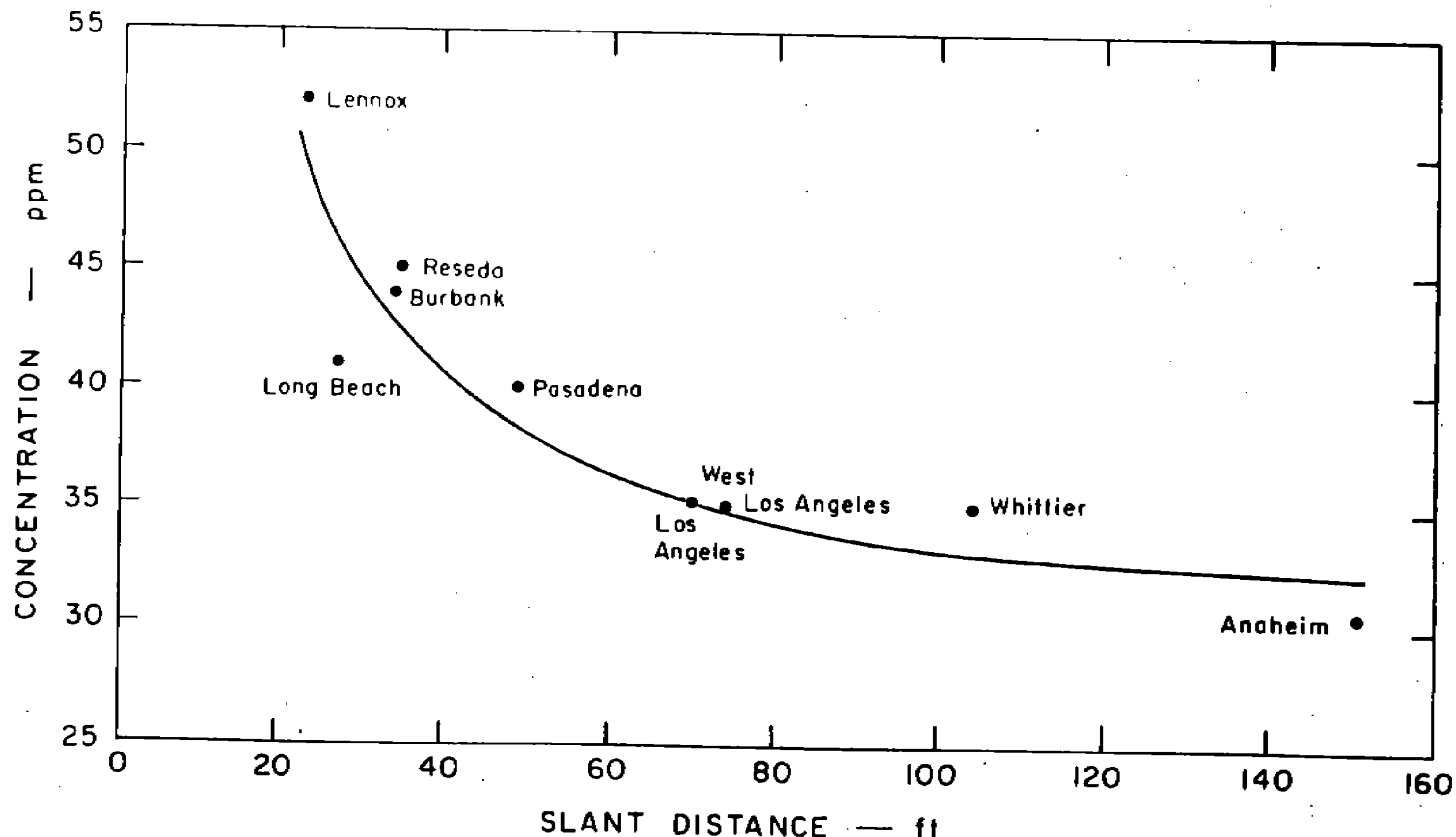
The simple model presented in Appendix A of this report was developed so that the relative importance of nearby, and more remote, sources could be evaluated. Application of the model can provide useful information concerning the degree to which a site represents the area that it is supposed to represent.

We have used the model with three sets of hourly meteorological data representing three different regions of the country. Conventional airport observations for the year 1960 were available from San Diego, California, and St. Louis, Missouri. Special observations made at Millstone, Connecticut were available for the period from late summer 1973 to late summer 1974. Thus, we have used meteorological data from the two coasts and the central United States.

Each set of meteorological data was used in combination with a hypothetical source distribution such as might be characteristic of an idealized, radially symmetric city. The particular distribution that was used for this problem decreased linearly from $1.3 \times 10^{-4} g/ m^2$ at the center to zero at 32 km from the center.

First, we investigated the effects associated with a street canyon monitor at five locations in the hypothetical city: at the center and at 17.5 km from the center in each of the cardinal directions. For the test, the street was chosen to be oriented in a northwest-southeast direction and to have traffic of 200,000 vehicles per day, emitting an average of 40 g of CO per mile. The street canyon was taken to be 20-m wide and 30-m deep. The inlet was specified to be 3-m high and 4-m from the traffic. The hypothesized daily traffic cycle (based on Roberts et al., 1971, nonfreeway data for Los Angeles) is shown in Figure 26. It shows the morning peak, sustained high midday values, a strong afternoon peak and a gradual decline to the very low post-midnight levels. No differentiation was made for weekends.

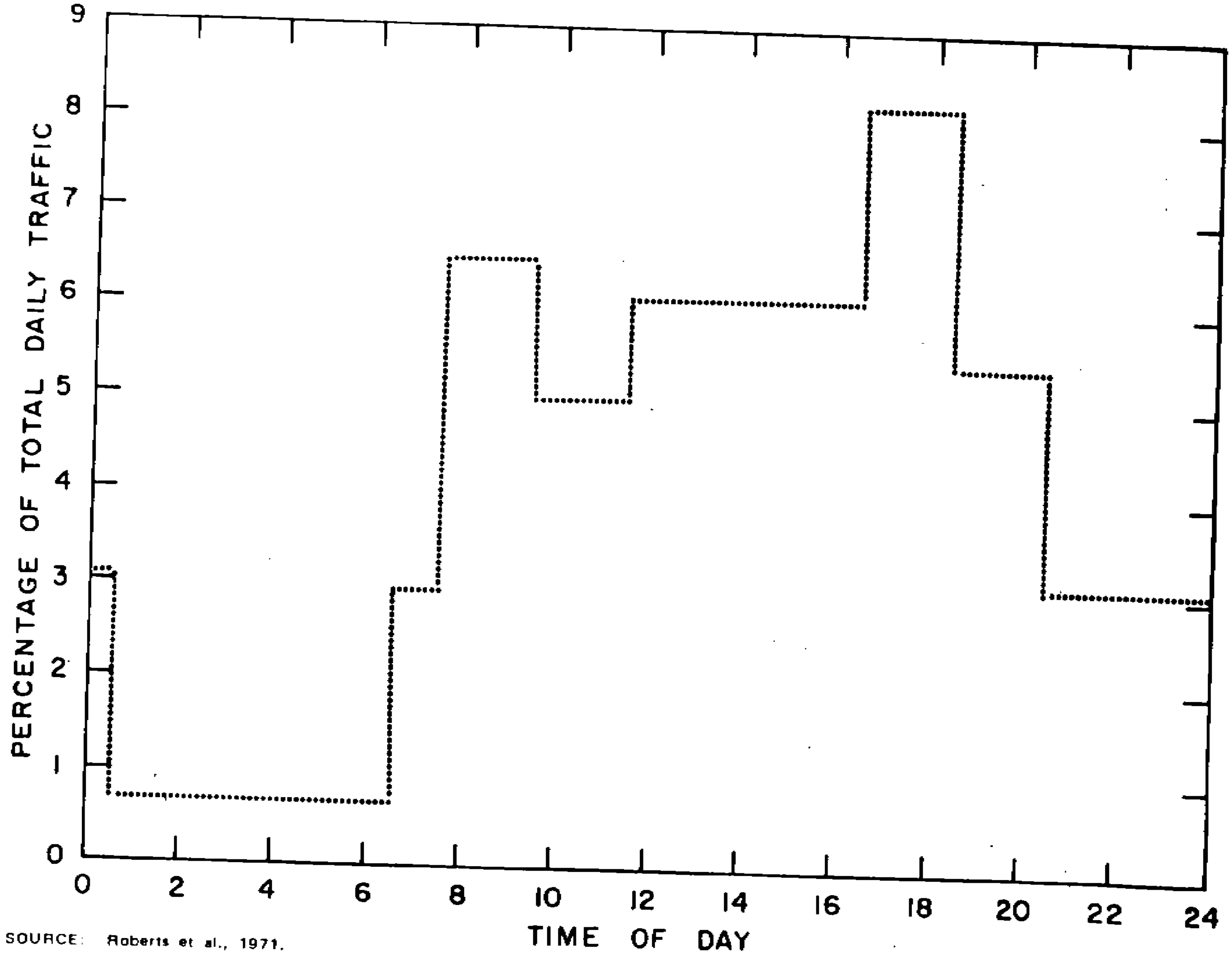
Figure 27 shows the frequency distributions of the contribution (to 8-hr average concentrations) of the local street relative to the contributions from the rest of the city. The figure shows that there are differences in the effect of the street that arise from differences in the climatology of the area, but these differences are not so great that generalizations cannot be made. For instance, the graphs show that at the center of the hypothetical city, the street contribution exceeds that from the rest of the city 20 to 30 percent of the time. The dominance of the local street increases as the monitor is moved toward the edge of the city. At 17.5 km from the center, the local street contribution exceeds that from elsewhere in the city 50 to 80 percent of the time, depending on the climatology and the direction from the city center to the site. Some differences in the importance of the local



SOURCE: Kinosian and Simeroth, 1973.

SA-3516-15

FIGURE 25 AVERAGES OF THE 1969-1970 ANNUAL MAXIMUM HOURLY CO CONCENTRATIONS VERSUS SLANT DISTANCES TO THE STREET



SOURCE: Roberts et al., 1971.

FIGURE 26 DAILY TRAFIC CYCLE (LOS ANGELES) street source are apparent from one side of the street to the other as can be seen in Figures 27c and 27d, but these differences are not as pronounced as those that are attributable to differences in location relative to the city center.

If the monitor is sufficiently removed from strong local sources, the city's emissions can be treated as area sources by the model described in Appendix A. When the model is applied in this way, it approximates the contributions to the CO concentrations monitored at a neighborhood or regional site. Figure 28 presents the frequency distribution of the ratios of the contributions from sources within 2 km to those at greater distances. As before, the model was applied to the hypothetical city emission distribution for locations at the city center and at radial distances of 17.5 km; the same three sets of hourly meteorological data were used.

The graphs in Figure 28 suggest that a substantial fraction of the CO concentrations observed at neighborhood sites will arise from sources within 2 km. There is considerable variablity, but sources within that range will contribute half, or more, of the observed CO on from 5 to 40 percent of the occasions. Differences in the importance of the nearer sources arise from meteorological factors and from the location relative to the center of the city. The number of instances in which the nearer sources contribute more than a third of the CO (i.e., the ratio of contributions from within 2km to those from greater distances exceeds 0.5) almost always exceeds, the number of instances when the nearer contributions are less than one third of the total.

The model confirms that nearby sources generally contribute a major portion of the observed CO concentrations at a point. Often the greatest concern is with those instances in which CO concentrations are the highest and a question arises concerning whether the contributions of the sources are as important during the periods of high concentrations as they are at other times. The model given in Appendix A identifies the 10 periods during the year when the calculated CO concentrations are highest. The frequency distribution of the ratios of street contributions to city-wide contributions for these "worst" 8-hour average cases is shown in Figure 29. In this figure the results from all the meteorogical data sets and from the different locations relative to the city center have been combined. Comparison of Figure 27 with Figure 29 suggests that during the periods of highest CO concentration, the contribution from the nearby street canyon is usually less than for other cases. In only a third of these "worst" cases do the street canyon emissions account for more than about a third of the total concentration. However, about two-thirds of the worst cases have contributions from the local street canyon that are more than 25 percent of the total.

For neighborhood type sites, the contributions from the nearest 2km were found to account for 15 to 40 percent of the total CO in virtually all cases. While this tends to be somewhat less than was true for the total population, it still constitutes a substantial fraction.

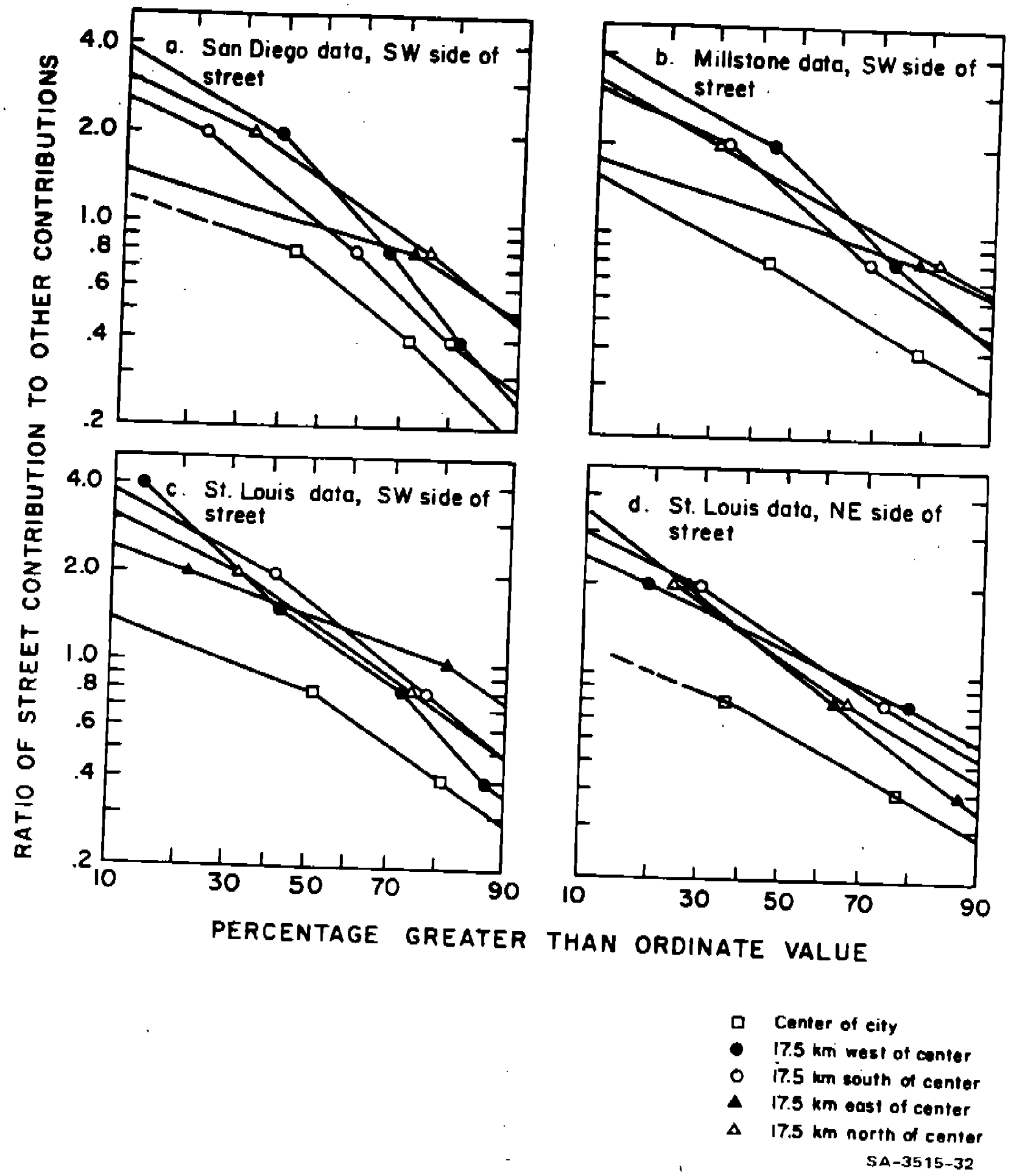


FIGURE 27 FREQUENCY DISTRIBUTIONS OF THE RATIOS OF STREET CONTRIBUTIONS TO CITYWIDE CONTRIBUTIONS FOR 8-HOUR AVERAGE CO CONCENTRATIONS

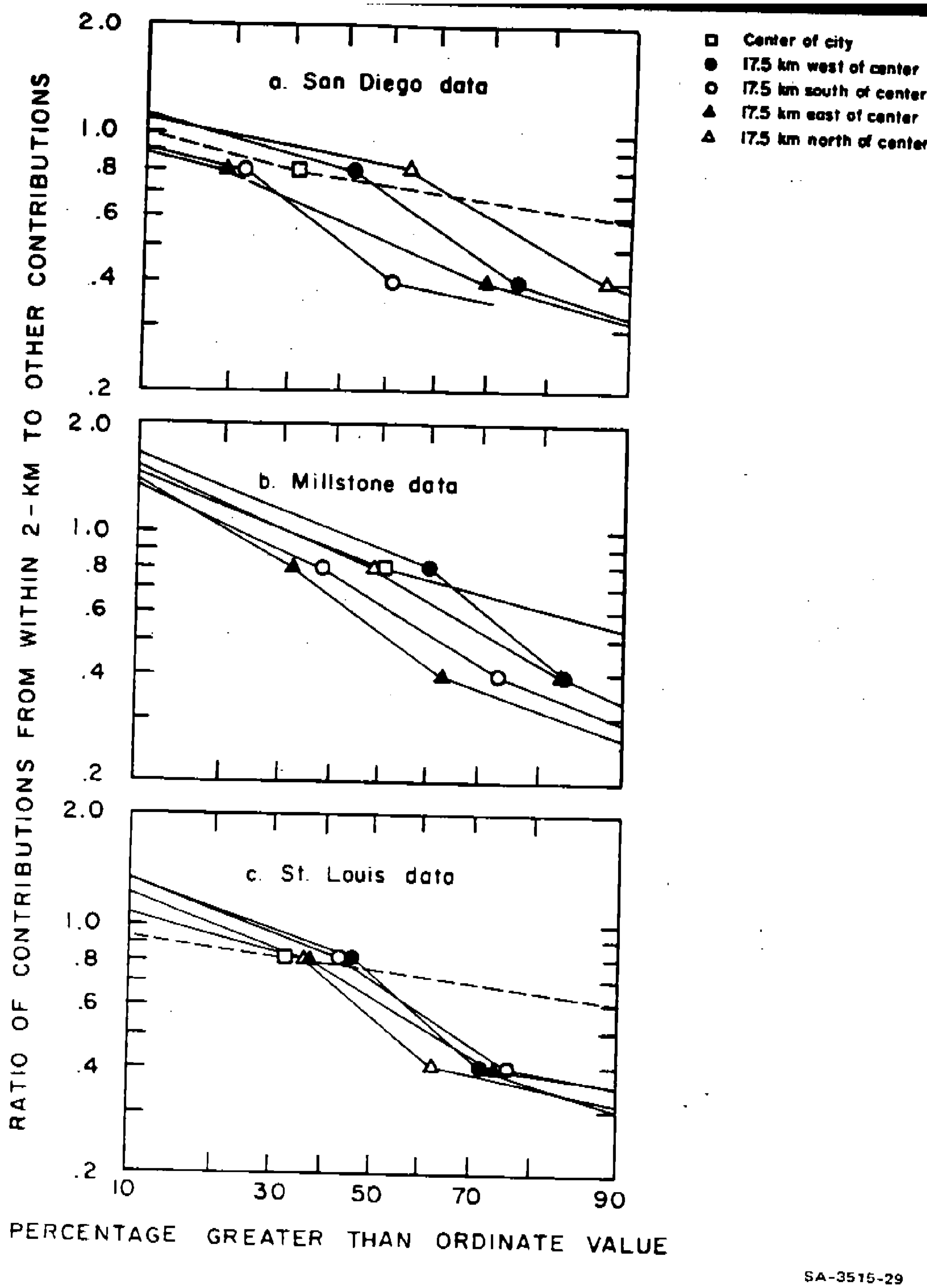


FIGURE 28 FREQUENCY DISTRIBUTIONS OF THE RATIOS OF CONTRIBUTIONS TO 8-HOUR CO CONCENTRATIONS FROM SOURCES NEARER AND FARTHER THAN 2 KM

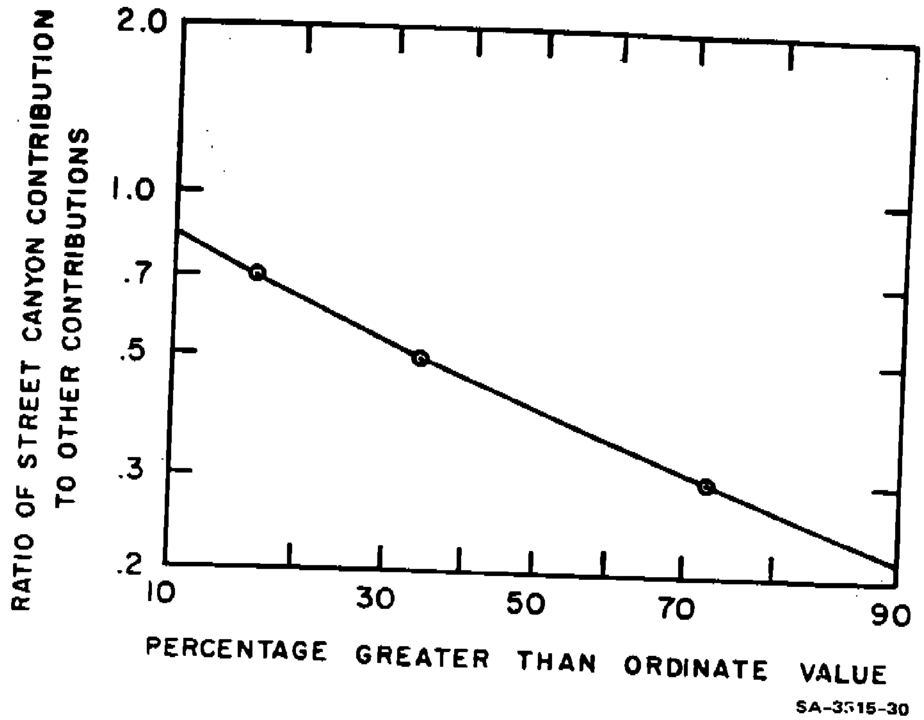


FIGURE 29 FREQUENCY DISTRIBUTION OF THE RATIOS OF STREET CONTRIBUTIONS TO CITYWIDE CONTRIBUTIONS FOR THE HIGHEST 8-HOUR AVERAGE CO CONCENTRATIONS

The results of the calculations, based on a hypothetical but reasonable distribution of emissions, confirm the importance of nearby sources in determining observed CO concentrations, in general, and during the occurrence of the highest concentrations. The variations from case to case indicate that calculations based on a particular distribution of emissions would be in order when there was concern about the effects observed at a specific site. Such calculations might be warranted at times other than during the initial siting process; calculations of the sort presented above would provide valuable guidance in the application of existing data, particularly in devising emission control strategies.

Emission control strategies would be much more efficient if they focused on those sources most responsible for violations of air quality standards. The results of the simulations presented earlier suggest that violations of the 8-hour air quality standard at a neighborhood station do not necessarily warrant the imposition of control measures throughout the urban region. Emission reductions in an area that is within a few kilometers of the site might be all that is needed to meet standards.

Violations of air quality standards at street canyon monitors might be the result of even more localized causes than those responsible at neighborhood sites. The control strategies required to meet standards at street canyon locations may only have to deal with streets that are within a few blocks of the monitor.

The preceding discussion of the importance of the sources at various distances from the monitor support the intuititve notion that siting criteria based largely on the distribution of sources near the monitor will be adequate to define, at least qualitatively, the spatial representativeness of the station. The argument comes full circle when we start deducing the influences of sources around a monitor from its type, as specified in terms of scales of representativeness. Finally, from the degree of influence exerted by various sources, we can deduce those areas that are the most important in reducing CO concentrations at the monitor. An important principle emerges—the application of the monitoring data should be consistent in spatial scale with the area represented by data from the site. Thus, if the concept of spatial representativeness is carefully applied during site selection, then the same concept can also be invoked for guidance when the data are later interpreted and applied as bases for finding solutions to practical problems.

Appendix A

A SIMPLE MODEL OF CONCENTRATION/EMISSION RELATIONSHIPS

Appendix A

A SIMPLE MODEL OF CONCENTRATION/EMISSION RELATIONSHIPS

A. Introduction

This appendix describes a simple pollutant concentration simulation model for inert, ground-level emissions. It can be used to process many hours of meteorological data economically and answer two practical questions:

- What sequence of meteorological conditions, from historical records, would have led to the highest multi-hour average concentrations at a given location?
- What are the relative contributions of sources at various distances to the observed multi-hour average concentrations?

The answer to the first question identifies critical periods so that they can be examined in greater detail. The problem of identifying "worst-case" conditions arises often when the air quality impacts of indirect sources are to be estimated. The second problem—that of evaluating the relative impact of sources at different distances--can arise during the site selection process for monitoring stations. The question of undue influence from certain sources is often an important issue.

The specific computer program described here has been designed to answer the two questions presented above, but the basic simple model itself should have application to a much broader variety of problems. It should be particularly suitable in any case where it is desirable to calculate a long sequence of concentrations very rapidly. The simple model also provides a very useful basis for qualitative understanding of the physical factors affecting concentrations at a site.

B. The Model

1. General

The model described here descends from the model proposed by Ott, Clarke, and Ozolins (1967) by way of the APRAC-1A model developed by Ludwig et al. (1970). The following discussion is derived largely from the latter source. Both models divide the upwind region into sectors, each of which is treated as a uniform, ground-level area source. The APRAC model uses geometrically spaced upwind intervals to provide better resolution for nearby sources. Figure A-1 shows the spatial partitioning that is used for the emissions. Nine segments are used, numbered from 1, for those sources within 125 m of the receptor, to 9, for those between 16 and 32 km from the receptor.

Concentrations are calculated from two basically different formulations. For sources near the receptor, a Gaussian model is used. This model postulates that unrestricted vertical diffusion of pollutants from ground-level line sources of infinite crosswind extent results in concentrations that have a Gaussian distribution of concentration in the vertical. The standard deviation, σ_z, of this distribution depends on such things as the atmospheric stability, and the distance downwind of the source. Several authors have proposed empirical relationships among σ_z, atmospheric stability and travel distance. Figure A-2 presents the Pasquill (1961), Gifford (1961) values, which are appropriate for rural conditions. Urban conditions differ from those in the country (Ludwig and Dabberdt, 1973), and for urban areas the curves in Figure A-3 are more appropriate. The urban relationships were derived by Johnson et al. (1971) from the work of McElroy (1969) and the Stanford Aerosol Laboratory (1952). In both instances, the relationships can be reasonably well approximated within each of the upwind segments by an expression of the form:

$$\sigma_z = a_{ij} r^{b_{ij}} \qquad (1)$$

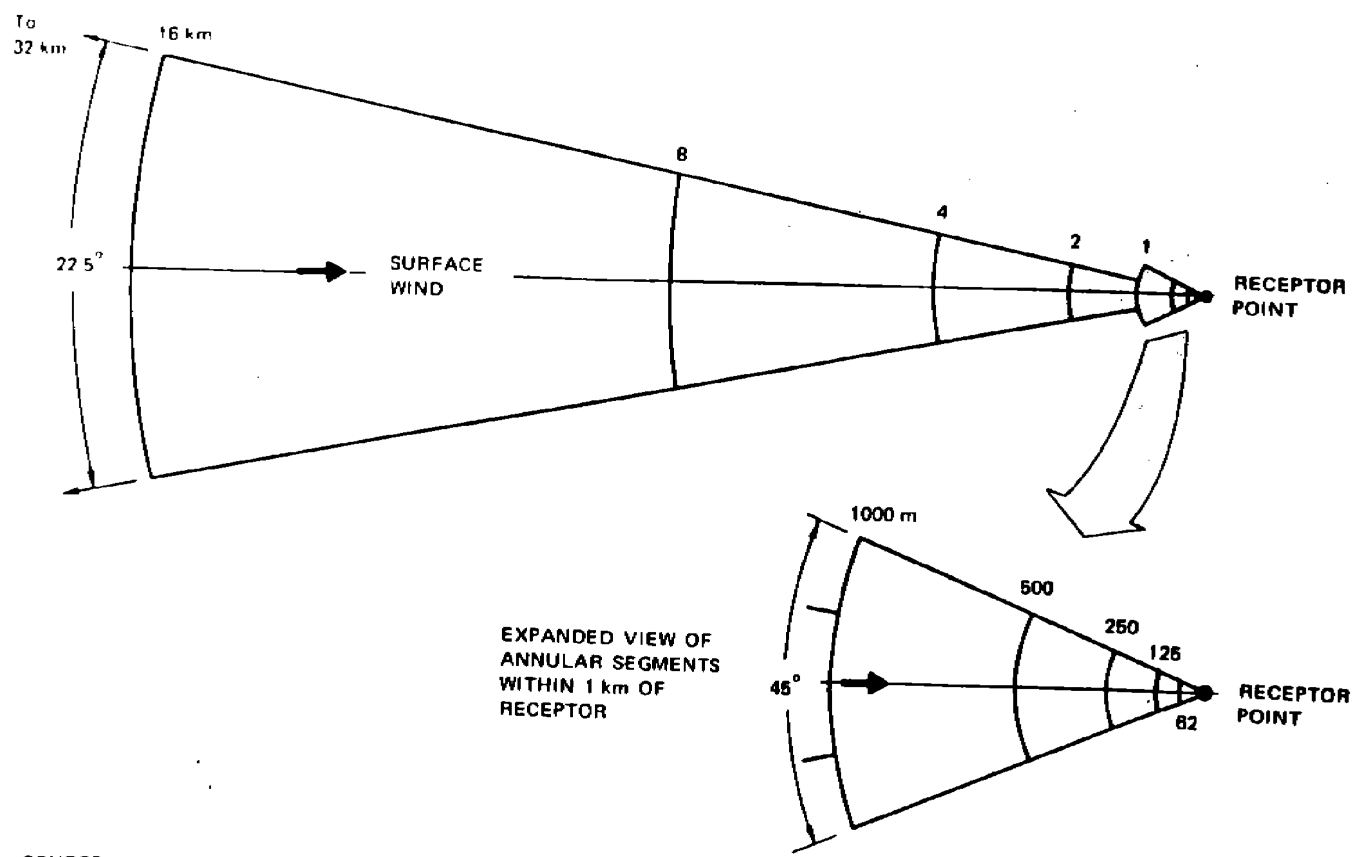
where r is the distance between the source and the receptor and a_{ij} and b_{ij} are constants applicable to upwind segment i and stability class j. This Gaussian model uses the following equation to calculate the concentration from one of the upwind segments in Figure A-1.

$$C_{ij} = \frac{0.8\ Q_i}{ua_{ij}} (1 - b_{ij})^{-1} \left(r_{i+1}^{1-b_{ij}} - r_i^{1-b_{ij}} \right) \qquad b_{ij} \neq 1$$

$$= \frac{0.8\ Q_i}{ua_{ij}} \ell n \left(\frac{r_{i+1}}{r_i} \right) \qquad b_{ij} = 1 \qquad (2)$$

where

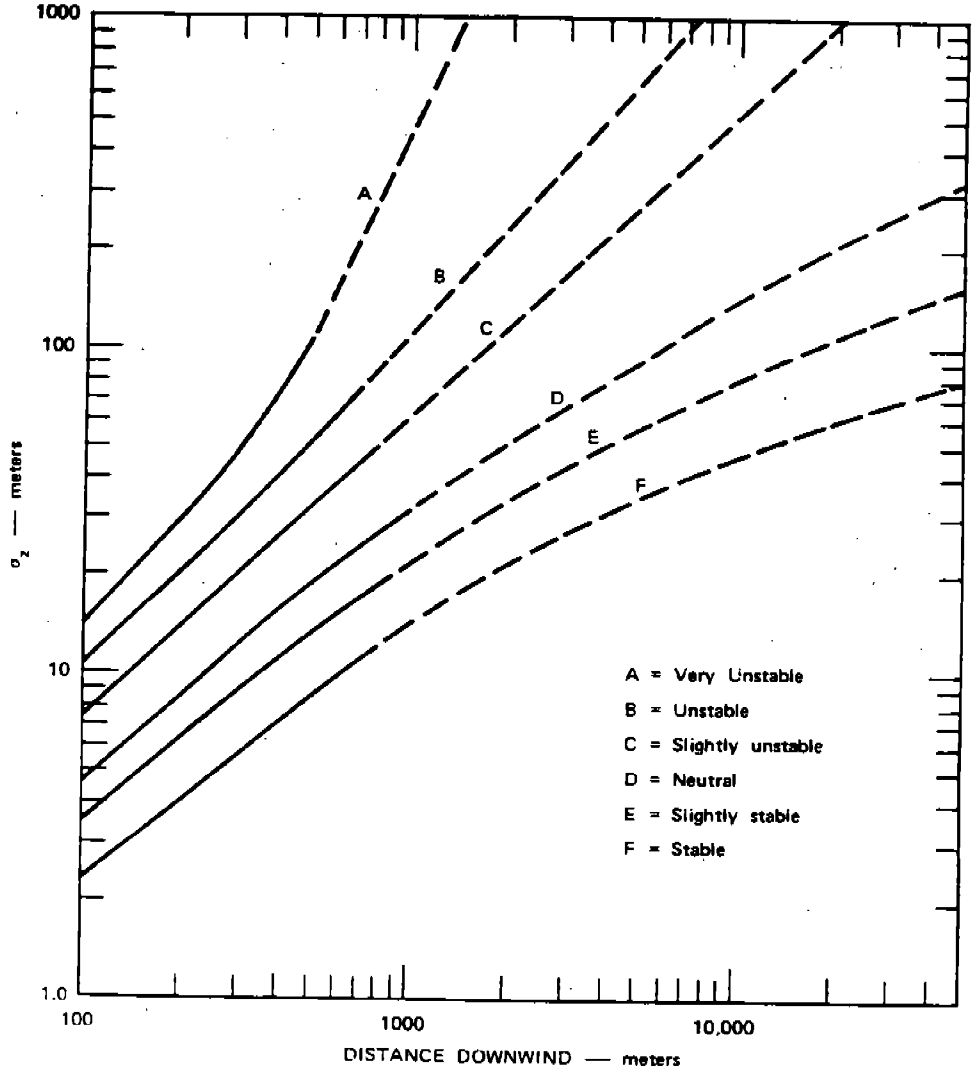
- C_{ij} = the ground-level concentration arising from the ith upwind segment for the jth stability class (gm/m^3)
- a_{ij}, b_{ij} = constants in Eq. (1) used to specify σ_z, the vertical standard deviation of dispersion.
- Q_i = emission rate in ith segment (gm/m s)
- r_i = distance to the downwind boundary of the ith segment (m)
- u = wind speed (m/s)



SOURCE: Johnson et al., 1971.

TA-7874-1R

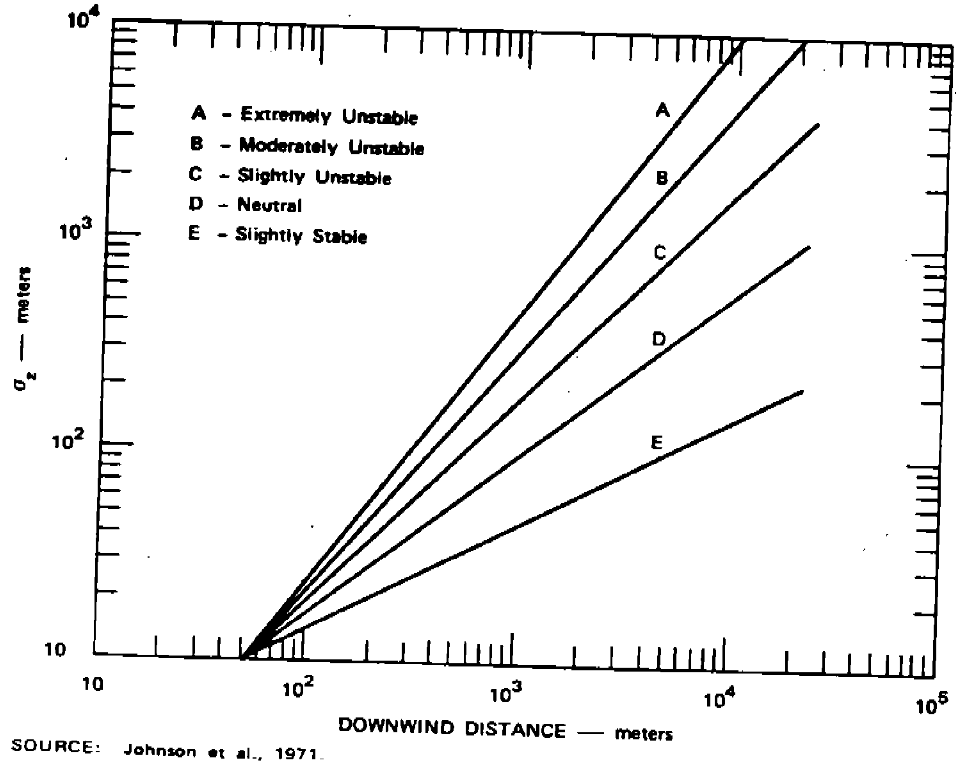
FIGURE A-1 DIAGRAM OF SEGMENTS USED FOR SPATIAL PARTITIONING OF EMISSIONS



SOURCE: Turner, 1970.

SA-3515-16

FIGURE A-2 VERTICAL DIFFUSION AS A FUNCTION OF TRAVEL DISTANCE AND STABILITY CATEGORY FOR RURAL AREAS



SOURCE: Johnson et al., 1971.

TA-8563-98R

FIGURE A-3 VERTICAL DIFFUSION AS A FUNCTION OF TRAVEL DISTANCE AND STABILITY CATEGORY FOR URBAN AREAS

When the layer into which the pollutants are being dispersed is restricted, they will tend to become uniformly distributed in the vertical after sufficient travel has taken place. Under these conditions, the "box" model can be used. According to the box model, the concentration arising from a uniform area source in the ith annular segment is defined by (see Miller and Holzworth, 1967):

$$C_i = \frac{r_{i+1} - r_i}{uh} Q_i \tag{3}$$

where h is the depth in meters of the layer into which the pollutants are mixed. When the box model is used, the concentration is independent of stability. The point of transition from the Gaussian to the box formulations occurs at that point where the two--in their line source formulations--would give equal concentrations. Using this criterion, the transition distance, r_T, is:

$$r_T = \left(\frac{0.8}{a_{ij}}\right)^{1/b_{ij}} \tag{4}$$

The composite model, defining the concentration that results from emissions in all the upwind segments, is given by:

$$C = \frac{1}{u} \left\{ \sum_{i=1}^{N-1} Q_i \left[\frac{0.8 \left(r_{i+1}^{1-b_{ij}} - r_i^{1-b_{ij}}\right)}{a_{ij} \, (1-b_{ij})} \right] + \right.$$

$$\left. Q_N \left[\frac{0.8 \left(r_T^{1-b_{Nj}} - r_N^{1-b_{Nj}}\right)}{a_{Nj} \, (1-b_{Nj})} + \frac{r_{N+1} - r_T}{h} \right] + \sum_{i=N+1}^{9} Q_i \left[\frac{r_{i+1} - r_i}{h} \right] \right\} \tag{5}$$

The transition from Gaussian to box models occurs at r_T in the Nth segment.

2. Simplifications

The rather simple model described by Eq. (5) can be further simplified if we take advantage of the finite number of atmospheric stability categories and introduce categories of mixing depth p_h and wind direction. Finally, we can assume that the source strengths in the different segments can be expressed as the product of a time-dependent factor and a time-independent factor.

$$Q_{i,d,t} = P_t \overline{Q}_{i,d} \qquad (6)$$

where

$Q_{i,d,t}$ = the source strength within the ith segment, in the dth direction, for the t th hour. $(g/m^2\ s)$

$\overline{Q}_{i,d}$ = the average daily source strength within the ith segment, in the dth direction $(g/m^2\ s)$

P_t = a factor that gives the source strength for the tth hour. P_t is assumed to be independent of location in the city, except that provision has been made in this model for using a different daily emission cycle for sources near, versus far from, the receptor.

If categories of mixing depth are introduced (see Table A-1), the model can be simplified to the following:

$$C = \frac{P_t}{u} \sum_{i=1}^{9} \left(\frac{\chi}{Q}\right)_{i,j,m} \qquad (7)$$

where

C = CO concentration at the receptor

u = wind speed

$(\chi/Q)_{i,j,m}$ = ratio of the CO concentration received from the ith segment to the emissions in that segment (for unit wind speed). The values of these ratios depend on stability class, j, and mixing depth class, m.

Values of $(\chi/Q)i,j,m$ calculated using a mixing depth equal to the geometric mean of the mixing depth class intervals in Table A-1 and rural σ_z functions from Slade (1968) are given in Table A-2. The values for urban σ_z 's (Johnson et al., 1971) were used to derive the values of $(\chi/Q)_{i,j,m}$ given in Table A-3. Table A-2 or Table A-3 will serve essentially as a model of pollutant concentration. Both tables indicate that contributions from sources within about 1/2 km are very nearly independent of mixing depth, while those from sources at greater distances are independent of atmospheric stability when the vertical mixing is sufficiently restricted. It is beyond the scope of this discussion to analyze the entries in the tables further.

Table A-1

MIXING DEPTH CLASSES

Mixing Depth Class	Mixing Depth Interval (meters)	Geometric Mean of Mixing Depth, Class
1	<100	70.7*
2	100–200	141
3	200–400	283
4	400–800	566
5	800–1600	1131
6	1600–3200	2262
7	>3200	4525*

* For classes 1 and 7, the geometric mean was calculated as though the classes were bounded.

However, note that the tables are quite revealing of the behavior of the model, and—to the extent that the model represents—the nature of the real atmosphere.

3. Special Model for Street Canyon Sources

The importance of nearby sources will be enhanced if the sources are confined in street canyons or other special situations. The model that is described here has a provision for treating street canyon effects, using the empirical submodel from the APRAC-1A model (Johnson et al., 1971; Ludwig and Dabberdt, 1972). For winds blowing toward the side of street on which the receptor is located:

$$C_{close} = \frac{KQ_s}{W(u+0.5)} \frac{H-z}{H} \quad \left\{ \begin{array}{l} \text{Wind blowing} \\ \text{toward receptor's} \\ \text{side of the street} \end{array} \right. \tag{8a}$$

where

C_{close} = contribution of close (street canyon) sources to the concentration.
H = depth of street canyon (m)
W = width of street canyon (m)
Q_s = emission rate on street (g/m s)
u = wind speed at roof level* (m/s)
z = height of receptor (m)
K = nondimensional empirical constant (approximately = 7)

* When airport winds are used, the term (u+0.5) is halved to approximate the effects of urban roughness in reducing wind speed.

Table A-2

CONTRIBUTIONS TO THE CONCENTRATION ($\mu g\ m^{-3}$) AT A POINT FROM EMISSIONS OF UNIT STRENGTH ($1\ \mu g\ m^{-2} s^{-1}$) AT VARIOUS UPWIND DISTANCE INTERVALS (FOR UNIT WIND SPEED -1 $m\ s^{-1}$)

RURAL

Stability Class*	Mixing Depth Interval	Upwind Distance Interval: 1-125 m	125-250 m	250-500 m	500-1000 m	1-2 km	2-4 km	4-8 km	8-16 km	16-32 km
1	<100 m	4.60	3.04	3.60	7.07	14.14	28.3	56.6	113.2	226.
2		6.89	4.92	4.99	7.07	14.14	28.3	56.6	113.2	226.
3		10.38	7.22	7.49	8.24	14.14	28.3	56.6	113.2	226.
4		16.11	11.91	13.48	15.74	19.17	28.5	56.6	113.2	226.
5		23.0	16.67	18.96	22.50	27.6	34.9	56.6	113.2	226.
1	100 to 200 m	4.60	3.04	2.62	3.54	7.07	14.14	28.3	56.6	113.2
2		6.89	4.92	4.99	4.60	7.07	14.14	28.3	56.6	113.2
3		10.38	7.22	7.49	8.08	8.79	14.14	28.3	56.6	113.2
4		16.11	11.91	13.48	15.74	19.17	24.2	31.5	56.6	113.2
5		23.0	16.67	18.96	22.5	27.6	34.9	47.1	67.4	113.2
1	200 to 400 m	4.60	3.04	2.61	1.96	3.54	7.07	14.14	28.3	56.6
2		6.89	4.92	4.99	4.55	4.03	7.07	14.14	28.3	56.6
3		10.38	7.22	7.49	8.08	8.75	9.65	14.16	28.3	56.6
4		16.11	11.91	13.48	15.74	19.17	24.2	31.1	42.0	60.5
5		23.0	16.67	18.96	22.5	27.6	34.9	47.1	67.4	100.3
1	400 to 800 m	4.60	3.04	2.61	1.58	1.77	3.54	7.07	14.14	28.3
2		6.89	4.92	4.99	4.55	3.60	3.54	7.07	14.14	28.3
3		10.38	7.22	7.49	8.08	8.75	9.65	10.89	14.50	28.3
4		16.11	11.91	13.48	15.74	19.17	24.2	31.1	42.0	59.3
5		23.0	16.67	18.96	22.5	27.6	34.9	47.1	67.4	100.3
1	800 to 1600 m	4.60	3.04	2.61	1.58	0.955	1.77	3.54	7.07	14.14
2		6.89	4.92	4.99	4.55	3.60	2.38	3.54	7.07	14.14
3		10.38	7.22	7.49	8.08	8.75	9.65	10.9	12.97	16.37
4		16.11	11.91	13.48	15.74	19.17	24.2	31.1	42.0	59.3
5		23.0	16.67	18.96	22.5	27.6	34.9	47.1	67.4	100.3
1	1600 to 3200 m	4.60	3.04	2.61	1.58	0.67	0.884	1.77	3.54	7.07
2		6.89	4.92	4.99	4.55	3.60	2.88	1.83	3.54	7.07
3		10.38	7.22	7.49	8.08	8.75	9.65	10.89	12.97	16.3
4		16.11	11.91	13.48	15.74	19.17	24.2	31.1	42.0	59.3
5		23.0	16.67	18.96	22.5	27.6	34.9	47.1	67.4	100.3
1	>3200 m	4.60	3.04	2.61	1.58	0.604	0.442	0.884	1.77	3.54
2		6.89	4.92	4.99	4.55	3.60	2.28	1.28	1.77	3.54
3		10.38	7.22	7.49	8.08	8.75	9.65	10.89	12.97	16.3
4		16.11	11.91	13.48	15.74	19.17	24.2	31.1	42.0	59.3
5		23.0	16.67	18.96	22.5	27.6	34.9	47.1	67.4	100.3

*
1 = extremely unstable
2 = moderately unstable
3 = slightly unstable
4 = neutral
5 = slightly stable.

Table A-3

CONTRIBUTIONS TO THE CONCENTRATION ($\mu gm\ m^{-3}$) AT A POINT FROM EMISSIONS OF UNIT STRENGTH ($1\ \mu gm\ m^{-2} s^{-1}$) AT VARIOUS UPWIND DISTANCE INTERVALS (FOR UNIT WIND SPEED -1 $m\ s^{-1}$)

URBAN

Stability Class*	Mixing Depth Interval	Upwind Distance Interval								
		1-125 m	125-250 m	250-500 m	500-1000 m	1-2 km	2-4 km	4-8 km	8-16 km	16-32 km
1	<100 m	2.9	2.0	3.5	7.1	14.1	28.3	56.6	113.2	226.3
2		3.4	2.3	3.5	7.1	14.1	28.3	56.6	113.2	226.3
3		4.0	2.8	3.6	7.1	14.1	28.3	56.6	113.2	226.3
4		4.8	3.6	4.3	7.1	14.1	28.3	56.6	113.2	226.3
5		6.2	5.2	7.3	10.3	14.9	28.3	56.6	113.2	226.3
1	100 to 200 m	2.9	1.9	1.9	3.5	7.1	14.2	28.4	56.7	113.5
2		3.9	2.2	2.1	3.5	7.1	14.2	28.4	56.7	113.5
3		4.0	2.8	2.9	3.6	7.1	14.2	28.4	56.7	113.5
4		4.8	3.6	4.3	5.0	7.1	14.2	28.4	56.7	113.5
5		6.2	5.2	7.3	10.3	14.4	20.2	29.6	56.7	113.5
1	200 to 400 m	2.9	1.9	1.5	1.8	3.5	7.1	14.1	28.3	56.5
2		3.4	2.3	2.0	2.0	3.5	7.1	14.1	28.3	56.5
3		4.0	2.8	2.9	2.9	3.6	7.1	14.1	28.3	56.5
4		4.8	3.6	4.3	5.0	5.9	7.4	14.1	28.3	56.5
5		6.2	5.2	7.3	10.3	14.4	20.2	28.4	39.9	58.8
1	400 to 800 m	2.9	1.9	1.5	1.3	1.8	3.5	7.1	14.1	28.3
2		3.4	2.3	2.0	1.8	1.9	3.5	7.1	14.1	28.3
3		4.0	2.8	2.9	2.9	3.0	3.6	7.1	14.1	28.3
4		4.8	3.6	4.3	5.0	5.9	6.9	8.2	14.1	28.3
5		6.2	5.2	7.3	10.3	14.4	20.2	28.4	39.9	56.0
1	800 to 1600 m	2.9	1.9	1.5	1.3	1.1	1.8	3.5	7.1	14.1
2		3.4	2.3	2.0	1.8	1.7	1.8	3.5	7.1	14.1
3		4.0	2.8	2.9	2.9	3.0	3.1	3.6	7.1	14.1
4		4.8	3.6	4.3	5.0	5.9	6.9	8.1	9.5	14.2
5		6.2	5.2	7.3	10.3	14.4	20.2	28.4	39.9	56.0
1	1600 to 3200 m	2.9	1.9	1.5	1.3	1.0	1.0	1.8	3.5	7.1
2		3.4	2.3	2.0	1.8	1.7	1.5	1.8	3.5	7.1
3		4.0	2.8	2.9	2.9	3.0	3.1	3.1	3.7	7.1
4		4.8	3.6	4.3	5.0	5.9	6.9	8.1	9.5	11.1
5		6.2	5.2	7.3	10.3	14.4	20.2	28.4	39.9	56.0
1	>3200 m	2.9	1.9	1.5	1.3	1.0	0.9	0.9	1.8	3.5
2		3.4	2.3	2.0	1.8	1.7	1.5	1.4	1.8	3.5
3		4.0	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.7
4		4.8	3.6	4.3	5.0	5.9	6.9	8.1	9.5	11.1
5		6.2	5.2	7.3	10.3	14.4	20.2	28.4	39.9	56.0

*1 = extremely unstable
2 = moderately unstable
3 = slightly unstable
4 = neutral
5 = slightly stable.

for the opposite side of the street:

$$C_{close} = \frac{KQ_s}{(u+0.5)(2+\sqrt{x^2+z^2})} \quad \left\{ \begin{array}{l} \text{Wind blowing away} \\ \text{from receptor's} \\ \text{side of the street} \end{array} \right. \qquad (8b)$$

where

x = horizontal distance from the receptor to the nearest lane of traffic (m)

Finally, when the wind blows within 30 degrees of the street alignment, the average of expressions (8a) and (8b) is used to calculate concentration.

C. Applications

Once a model is available to calculate hour-by-hour concentrations from near and far sources, then it is possible to apply methods generally reserved for use with observed monitoring data. In particular, it is possible to consider multi-hour averages directly and without resort to statistical models. In this subsection, some specific applications of this type will be considered briefly. One such application is the identification of "worst-cases" for different averaging periods. The sequence of calculated near and far contributions, can be scanned and running means determined. The highest values are easily identified along with the time interval during which they occurred. Once a limited number of candidate worst cases have been identified, then the specific cases can be studied in more detail and with more comprehensive models.

Air quality impact assessments often require that "most probable" and "worst" cases be identified and the impact of some unbuilt complex be determined for these two categories. We will first consider the "worst" case. "Worst" will depend on some unique distribution of sources (often, as yet unbuilt), daily emission cycles, and sequences of meteorological conditions. Because of differences in the surrounding sources, the "worst" periods may not occur everywhere at the same time. Therefore, it may not be possible to identify worst conditions on the basis of observations taken at established monitoring sites, and the simple model provides a useful tool.

For single-hour averages, the most probable and worst cases are easily defined as the most common combination of stability, mixing height, wind speed and wind direction, and the observed combination that produces the highest concentrations, respectively. Identification of the worst cases was discussed above; identification of the most probable cases would probably require some subjective analysis by a professional meteorologist, but the model could be used to reduce the complete set of conditions down to some smaller subset that contained all those instances when calculated concentrations fell within some specified interval around the mode. The general meteorological conditions that accompany these instances could be studied and classified and perhaps one, or a few, "most probable" prototypes could be selected for detailed analysis.

Site selection for monitoring stations sometimes requires that the measurements be representative of a large area and, in other instances it is desirable to monitor the effects of nearby sources. Thus, it may be desirable to evaluate the relative contributions of sources at various distances from a proposed monitoring site. If multi-hour averages are of importance, such as might be the case when a site is serving to determine compliance with federal or state air quality standards, this model can provide a method for solving the problem. Running means can be calculated for the contributions from near sources and from more remote sources. The contributions from the two areas can be compared by calculating the average of their ratios, the frequency distributions of the ratios, or the average of their differences; all are possible approaches to the comparisions, once the running means are available.

The following subsection describes a computer program that was written to use the model presented above to identify worst cases and to calculate a frequency distribution for the ratio of the contributions of near and far sources to receptor concentration. The program listing, in Control Data FORTRAN Version 2.1, is given at the end of this appendix.

D. Computer Program

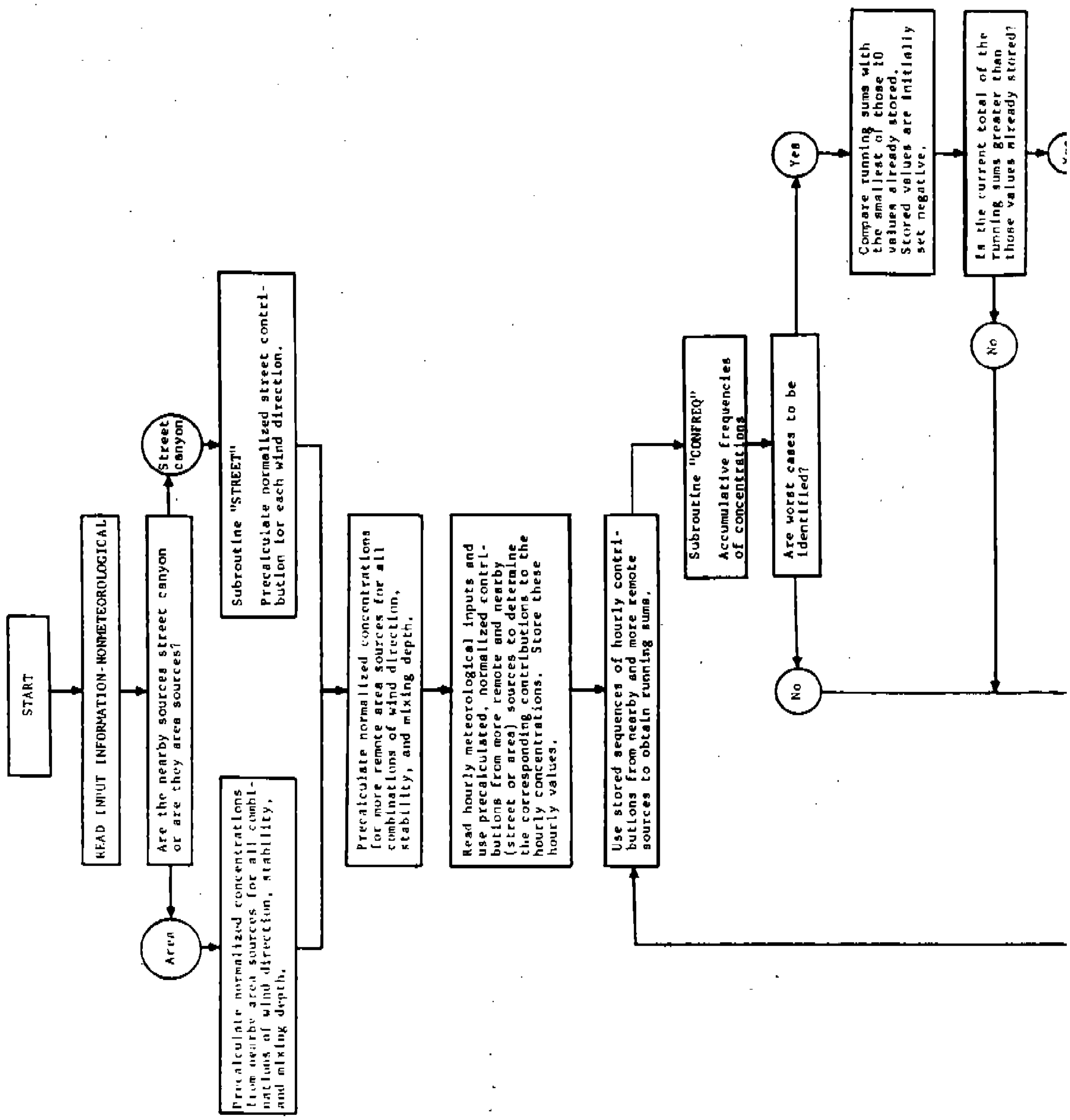
A simplified flow chart of the program SMOCER (simple model of concentration-emissions relationships) is shown in Figure A-4. Many calculations are made in the initial stages and the resulting values are stored for subsequent use. Once these preliminary calculations are complete, hourly meteorological data is read and used to calculate hourly concentrations, with the contributions from near and far sources treated separately. The listing included here has provisions for reading the meteorological inputs from tape with the program modifications necessary to use card inputs given as comments. Modification of the program might be required for use on small computers. The version given here stores hourly values of the several pertinent parameters for a period up to one year. After the values are all stored, running sums and other calculations are made. If storage were limited, such calculations could be made sequentially as the hourly values were obtained. Such a modification should not be particularly difficult.

The program is capable of obtaining two different kinds of output from the sequence of hourly results. First, it can identify the ten worst cases for the period. Initially, no restrictions were placed on the selection process except that the highest multi-hour averages were to be chosen. In practice, several of the worst cases will overlap.

That is, the multi-hour averages for several cases may include some of the same hours. Since it was intended that the identified cases be relatively independent, overlapping cases are no longer considered. If a sequence of high values of running means occurs, and they are separated by less than the averaging interval being used, only the highest value will be chosen even though other values in the sequence might exceed some of the retained high values from other parts of the total list. After all the data have been treated, the model will produce a list of the ten highest running mean concentrations (with the restrictions noted above) and the day and last hour of the corresponding averaging period.

The program will also calculate the ratio of the contributions from near sources to those from sources farther away, again based on multi-hour running means.

Table A-4 lists the FORTRAN variables used in the program and their meaning, and Table A-5 gives the input requirements for using the program. This is followed by the program listing. During the course of this study the program was applied with Los Angeles inputs using one year of hourly data on tape. The costs, using a CDC 6400 computer, were less than four dollars, including compilation of the program. Central processor time, excluding compilation, was less than 13 seconds.


START
READ INPUT INFORMATION-NONMETEOROLOGICAL
Are the nearby sources street canyon or are they area sources?
Street canyon
Area
Subroutine "STREET"
Precalculate normalized street contribution for each wind direction.
Precalculate normalized concentrations from nearby area sources for all combinations of wind direction, stability, and mixing depth.
Precalculate normalized concentrations for more remote area sources for all combinations of wind direction, stability, and mixing depth.
Read hourly meteorological inputs and use precalculated, normalized contributions from more remote and nearby (street or area) sources to determine the corresponding contributions to the hourly concentrations. Store these hourly values.
Use stored sequences of hourly contributions from nearby and more remote sources to obtain running sums.
Subroutine "CONFREQ"
Accumulative frequencies of concentrations
Are worst cases to be identified?
Yes
No
Compare running sums with the smallest of those 10 values already stored. Stored values are initially set negative.
Is the current total of the running sums greater than those values already stored?
No

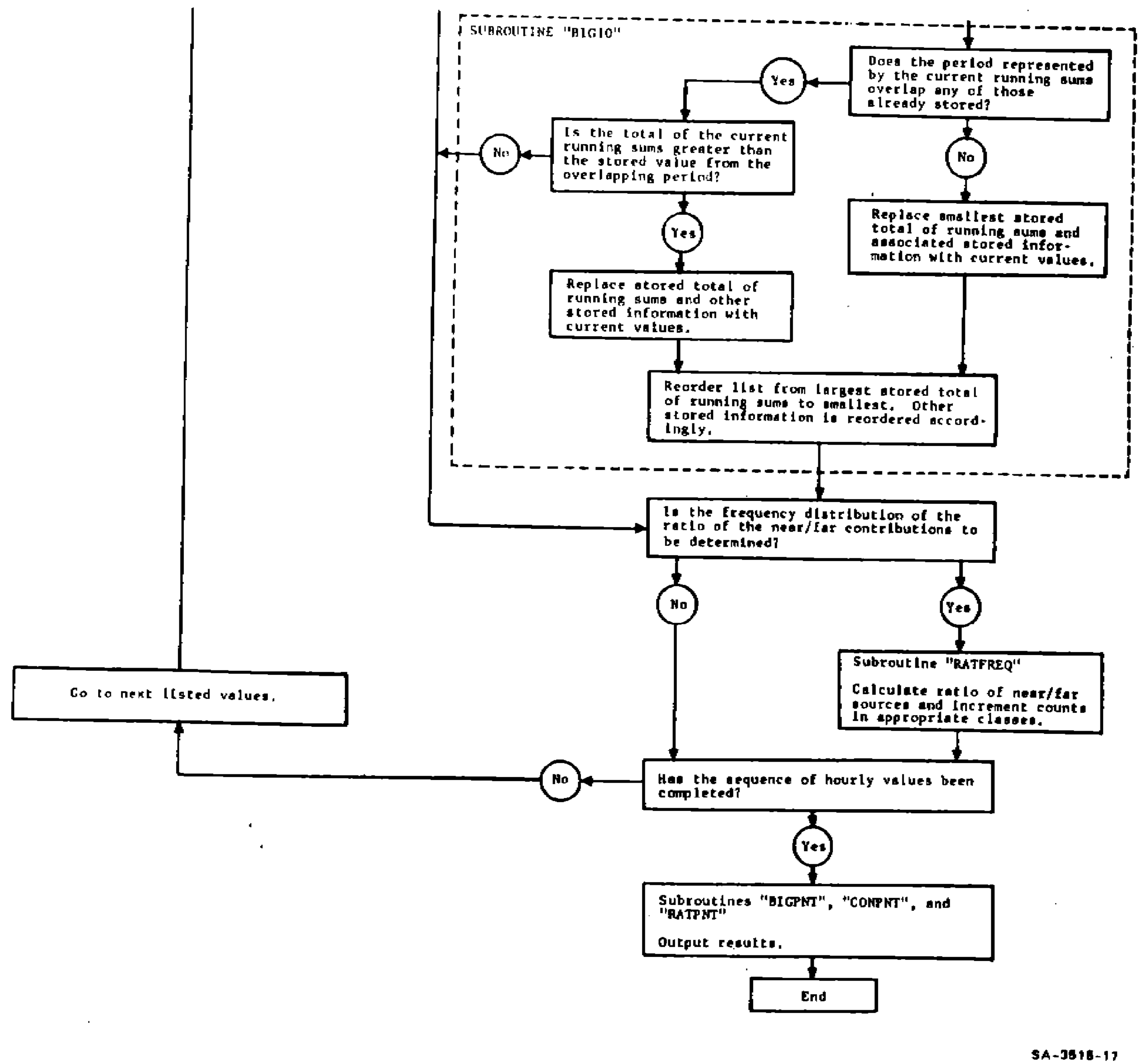


FIGURE A-4 (continued). SIMPLIFIED FLOW CHART OF COMPUTER PROGRAM

Table A-4

FORTRAN VARIABLES USED IN SMOCER

ADT	= Average daily traffic (vehicles/day).
ANGLE	= Angle normal to STDIR.
CFAR	= Far concentration array.
CLEE	= Concentration with unit wind speed for receptor facing away from the wind direction.
CLOSTYP	= Type of source near receptor (street or area).
CMILGM	= Average concentration mg/m³.
CNEAR	= Near concentration array.
COS6∅	= Cosine of 6∅ degrees.
CWIND	= Concentration with unit wind speed for receptor facing toward the wind direction.
DP	= Dewpoint (not used, but on meteorological tape).
DT	= Temperature (not used, but on meteorological tape).
EMRATE	= Average vehicular emission rate (g/veh.-mi.).
FACTOR	= Used to convert emissions in g/mile-day to g/m s.
I	= Mixing depth index.
IDIR	= Upwind direction (1 = north, ...16 = north-northwest, 0 = calm).
IHR	= Hour index.
ISEG	= Upwind segment index.
ISTAB	= Stability index.
MEANHR	= Averaging interval for running means (hrs).
MHR	= Hour (of NDAY) of end of averaging interval for a high concentration case.
NCLOSE	= Number of segments to be considered as near when CLOSTYP = areas; when CLOSTYP = Street, then NCLOSE = 1.
NDAY	= Number of the day in which last hour of averaging interval occurs for a high concentration case.
NHR	= Last hour of averaging period (running sequentially from first hour) of the highest concentrations.
NN	= Number of hours since start.
OC	= Opaque cloud cover (not used but on meteorological tape).
OUTPUT	= Type of calculations to be performed.
PPM	= Average concentration (parts per million).
PTFAR	= Fraction of far source emissions occurring during hour.
PTNEAR	= Fraction of near source emissions occurring during hour.
QST	= Emission rate on street (g/m s).
RATIO	= Frequencies of ratios of NEAR/FAR source contributions.

Table A-4 (concluded)

FORTRAN VARIABLES USED IN SMOCER

SI	= Stability index (1 = extremely unstable ... 5 = slightly stable).
SIDE	= Side (left or right) of receptor when facing STDIR.
STDIR	= Street direction (degrees from north).
TOPRAT	= Ratios of NEAR/FAR contributions—during same periods as the highest concentrations.
TOP10	= Ten highest multi-hour concentrations.
VALUE	= Class boundaries for cumulative frequency distribution. (number greater than . . .).
WD	= Wind direction (16 directions, 1 = NNE...16 = N, 0 = Calm).
W,H	= Width and height of street canyon (m).
WS	= Wind speed (m/s).
Z,X	= Height and horizontal distance of receptor from near traffic lane (m).

Table A-5

INPUTS FOR A SIMPLE MODEL OF CONCENTRATION/EMISSION RELATIONSHIPS

Card Number	Variables	Format	Remarks
1	Problem identification, up to 80 characters	16A5	Whatever this card contains is printed with outputs for identification
2	CLØSTYP (either "STREET" or "AREAS")	A10	Must start at Column 1, identifies whether close source uses street canyon model
	OUTPUT ("RATIO," "WORST," or "BOTH")	A10	Calculates only ratios, only worst cases, or both, depending on this input. Must start at Column 11
	MEANHR	I5	Number of hours for averaging
	NCLØSE	I5	If Clostyp not "STREET" tells how many segments are considered as "near"
2A	ADT	F8.1	Average daily traffic-vehicles/day
This card used only if CLØSTYP = STREET	EMRATE	F8.1	Emission rate g/vehicle-mile
	STDIR	F8.1	Street direction, degrees from north
	SIDE ("LEFT" or "RIGHT")	A8	Starts at Column 25-side when facing STDIR
	W, H	2F8.1	Street canyon width, height (m)
	Z, X	2F8.1	Vertical, horizontal distances (m) to nearest traffic
3-7	XØQ values for 9 segments on one card, cards for stability classes 1-5, 1st mixing category	9F8.1	Cards 3 through 12 contain concentration/emission ratios from Tables A-2 or A-3
8-12	XØQ-stability classes 1-5, 2nd mixing category	9F8.1	Same as Cards 3-7.
13-28	Q	9E8.1	16 cards containing emission rates (g/m^2-s), 9 segments on a card, one card for each direction 1, 16
29-31	PTNEAR fraction of daily traffic/hour	8F10.3	From near sources (or street), hours run from 1 to 24
32-34	PTFAR fraction of daily traffic/hour	8F10.3	From far sources, hours run from 1 to 24
35	MIXTYP mixing type to be used with XOQ	24I2	24 values (either 1 or 2) for each hour from 1 to 24
36...	Meteorological inputs follow, either from tape or cards, see program listing.		

PROGRAM LISTING

```
      PROGRAM SMOCER (INPUT,OUTPUT,TAPE1)
C
C**********THIS SIMPLE MODEL OF CONCENTRATION RELATIONSHIPS IDENTIFIES
C**********THE WORST CASES FOR DIFFERENT AVERAGING INTERVALS AND THE
C**********RELATIVE CONTRIBUTIONS FROM NEAR AND FAR SOURCES.
C**********F.L.LUDWIG AND H. SHIGIESHI.
C
      DIMENSION XQQ(9,5,2),Q(9,16),CNEAR(8784),CFAR(8784),CNNORM(5,16,2)
     1,CFNORM(5,16,2),PTNEAR(24),PTFAR(24),MIXTYP(24),WD(24),WS(24),
     1SI(24)
      COMMON /TOP/ NN,CTOT,CLOSC,FARC,TOP10(10),NHR(10),TOPRAT(10),
     1COFREQ(10)
      COMMON /VAR/ XNORM,QST,SIDE,IDIR,STDIR,W,H,Z,X
      COMMON /RAT/ RATIO,FREQ(10),VALUE(10)
      COMMON /DAT/ ALPHA(16),MEANHR,CLOSTYP,NCLOSE
 1    FORMAT (1H1,35X*STREET AIR POLLUTION ANALYSIS.*/)
 2    FORMAT (16A5)
 3    FORMAT (1H ,16A5)
 4    FORMAT (2A10,2I5)
 5    FORMAT (1H ,*CLOSTYP = *A10,5X*OUTPUT = *A10,5X*MEANHR =*I5,5X
     1*NCLOSE =*I5/)
 6    FORMAT (3F8.1,A8,4F8.1)
 7    FORMAT (1H ,*ADT =*F8.2,3X*EMRATE =*F8.2,3X*STDIR =*F8.2,3X*SIDE =
     1*, A8,3X*W =*F8.2,3X*H =*F8.2,3X*Z =*F8.2,3X*X =*F8.2)
 8    FORMAT (//1H ,50X*NORMALIZED CONCENTRATION/EMISSION*/1H ,*STABILIT
     1Y/SEGMENTS*,9I10)
 9    FORMAT (1H ,I5,13X9E10.3)
 10   FORMAT (//1H ,50X*EMISSIONS*/1H ,*DIRECTION/SEGMENTS*9I10)
 11   FORMAT (24I2)
 12   FORMAT (//1H ,12X*PERCENT*8X*PERCENT*/1H ,*HOUR*5X*(ADT CLOSE)*7X,
     1*(ADT FAR)*2X*MIX TYPE*)
 13   FORMAT (1H ,I2*00*2F15.5,I10)
 14   FORMAT (/1H ,*OUTPUT SPECIFICATION ERROR*)
 15   FORMAT (8F10.3)
 17   FORMAT (9F8.1)
 18   FORMAT (9E8.1)
C
C**********FACTOR IS USED TO CONVERT EMISSIONS IN GM/MILE-DAY TO
C********** (GM/M-S)
C
      FACTOR = 1.0/(1609.35*3600.0*24.0)
C
C**********READ IDENTIFYING HEADING
C
      PRINT 1 $ READ 2,ALPHA $ PRINT 3,ALPHA
C
C**********READ TYPES OF CALCULATION TO BE PERFORMED.
C**********     CLOSTYP=TYPE OF SOURCE NEAR RECEPTOR (STREET OR AREAS).
C**********     OUTPUT=TYPE OF CALCULATIONS TO BE PERFORMED...
C**********       RATIO--FIND FREQUENCIES OF RATIOS OF NEAR/FAR SOURCE
C**********       CONTRIBUTIONS.
C**********       WORST--FIND 10 HIGHEST CONCENTRATIONS.
C**********       MEANHR--AVERAGING INTERVAL FOR RUNNING MEANS (HOURS).
C**********       NCLOSE--NUMBER OF SEGMENTS TO BE CONSIDERED AS NEAR
C**********       WHEN CLOSTYP=AREAS. WHEN CLOSTYP=STREET, THEN NCLOSE=1
C
      READ 4,CLOSTYP,OUTPUT,MEANHR,NCLOSE
      PRINT5,CLOSTYP,OUTPUT,MEANHR,NCLOSE
      MCLOSE=NCLOSE+1
      IF (CLOSTYP.NE.6HSTREET) GO TO 100
```

```
C
C**********FOR STREET CASE READ
C**********      ADT=AVERAGE DAILY TRAFFIC (VEHICLES/DAY)
C**********      EMRATE = AVERAGE VEHICULAR EMISSION RATE (GM/VEH-MI)
C**********      STDIR = STREET DIRECTION (DEGREES FROM NORTH)
C**********      SIDE = SIDE (LEFT OR RIGHT) OF RECEPTOR WHEN FACING STDI
C**********      W,H = WIDTH AND HEIGHT OF STREET CANYON (M)
C**********      Z,X = HEIGHT AND DISTANCE OF RECEPTOR FROM NEAR TRAFFIC
C**********      LANE (M)
C
      READ 6,ADT,EMRATE,STDIR,SIDE,W,H,Z,X
      PRINT7,ADT,EMRATE,STDIR,SIDE,W,H,Z,X
C
C**********QST=EMISSION RATE ON STREET (24*GM/M-S).  NCLOSE=1, MCLOSE=2
C**********MEANS THAT THE STREET REPLACES THE 1ST SEGMENT AS THE NEAR
C**********SOURCE.
C
      QST=ADT*EMRATE*FACTOR $ NCLOSE=1 $ MCLOSE=2
 100  PRINT 8,(L,L=1,9)
C
C**********READ RATIOS OF CONCENTRATION TO EMISSIONS(XOQ--S/M) AT UNIT
C**********WIND SPEED(M/S) FOR VARIOUS UPWIND SEGMENTS (ISEG), STAB-
C**********ILITIES (ISTAB) AND MIXING DEPTH CLASSES (I).
C
      READ 17,(((XOQ(ISEG,ISTAB,I),ISEG=1,9),ISTAB=1,5),I=1,2)
      PRINT 9,((ISTAB,(XOQ(ISEG,ISTAB,I),ISEG=1,9),ISTAB=1,5),I=1,2)
      PRINT 10,(L,L=1,9)
C
C**********READ EMISSIONS (Q--GM/M*M*S) IN DIFFERENT UPWIND DIRECTIONS
C**********(IDIR) AND SEGMENTS (ISEG).
C
      READ 18,((Q(ISEG,IDIR),ISEG=1,9),IDIR=1,16)
      PRINT 9,(IDIR,(Q(ISEG,IDIR),ISEG=1,9),IDIR=1,16)
C
C**********READ FRACTION OF DAILY TRAFFIC OCCURRING DURING EACH HOUR
C**********(IHR) FOR NEAR(PTNEAR) AND FAR(PTFAR) SOURCES.
C
      READ 15,(PTNEAR(IHR),IHR=1,24)
      READ 15,(PTFAR (IHR),IHR=1,24)
C
C**********READ MIXING DEPTH TYPE FOR EACH HOUR.
C
      READ 11,(MIXTYP(IHR),IHR=1,24)
      PRINT 12
      PRINT 13,(IHR,PTNEAR(IHR),PTFAR(IHR),MIXTYP(IHR),IHR=1,24)
      IF (CLOSTYP.EQ.6HSTREET) GO TO 125
C
C**********CALCULATING NORMALIZED CONCENTRATIONS FROM NEAR, NON-STREET
C**********SOURCES.
C
      DO 120 IDIR=1,16
      DO 115 ISTAB=1,5
      DO 110 J=1,2
      SUMCN=0.0
      DO 105 ISEG=1,NCLOSE
      SUMCN=SUMCN+XOQ(ISEG,ISTAB,J)*Q(ISEG,IDIR)
 105  CONTINUE
      CNNORM(ISTAB,IDIR,J)=SUMCN
 110  CONTINUE
 115  CONTINUE
 120  CONTINUE
      GO TO 145
C
C**********CALCULATING NORMALIZED CONCENTRATIONS FROM STREET SOURCE FOR
C**********UNIT WIND SPEED.
C
 125  DO 140 IDIR=1,16
```

```
      CALL STREET
C
C**********STREET CONCENTRATIONS ARE INDEPENDENT OF STABILITY AND MIX-
C**********ING DEPTH
C
      DO 135 ISTAB=1,5
      DO 130 J=1,2
      CNNORM(ISTAB,IDIR,J)=XNORM
  130  CONTINUE
  135  CONTINUE
  140  CONTINUE
  145 DO 165 IDIR=1,16
      DO 160 ISTAB=1,5
      DO 155 J=1,2
      SUMCF=0.0
C
C**********CALCULATING NORMALIZED CONCENTRATIONS FROM FAR SOURCES.
C
      DO 150 ISEG=MCLOSE,9
      SUMCF=SUMCF+XOQ(ISEG,ISTAB,J)*Q(ISEG,IDIR)
  150 CONTINUE
      CFNORM(ISTAB,IDIR,J)=SUMCF
  155 CONTINUE
  160 CONTINUE
  165 CONTINUE
      NN=0
C
C**********FILL CONCENTRATION ARRAYS (8784 HOURS=1 LEAP YEAR), NEAR
C**********(CNEAR)AND FAR(CFAR) WITH NEGATIVE VALUES
C
      CALL MEMSETX (-99.0,CNEAR,8784)
      CALL MEMSETX (-99.0,CFAR ,8784)
C
C**********READ 24 HOURS OF METEOROLOGICAL DATA...
C**********       WD=WIND DIRECTION(16 DIR., 1=N...16=NNW...0=CALM)
C**********       WS=WIND SPEED (M/S)
C**********       DT,DP,DC=TEMPERATURE,DEWPOINT, CLOUD ..NOT USED.
C**********       SI=STABILITY INDEX (1=EXTREMELY UNSTABLE....5= SLIGHT-
C**********       LY STABLE)
C
  170 READ (1) STANO,DATE,(WD(L),WS(L),DT,DP,DC,SI(L),L=1,24)
      IF (EOF(1)) 200, 175
C
C**********FOLLOWING CARDS  CAN BE USED (WITHOUT COMMENTS) TO READ
C**********METEOROLOGICAL DATA FROM CARDS.
C 170 DO 171 L=1,24
C     READ 16,          WD(L),WS(L),DT,DP,DC,SI(L)
C  16 FORMAT (6F4.1, 56X )
C     IF (WD(L) .LT. 0.0 ) GO TO 200
C 171 CONTINUE
C
 175  DO 195 IHR=1,24
C
C**********NN=NUMBER OF HOURS SINCE START.
C
      NN = NN+1
C
C**********SKIP MISSING DATA...NEGATIVE VALUES.
C
      IF (WD(IHR).LT.0.0.OR.WS(IHR).LT.0.0.OR.SI(IHR).LT.0.0) GO TO 195
      J=MIXTYP(IHR)
      ISTAB=SI(IHR)
```

```
C**********CALM WINDS SET= 1 M/S AND MOST RECENTLY OBSERVED DIRECTION.
C
      IF (WD(IHR).EQ.0.0) GO TO 180
      IF (WS(IHR).LT.1.0) WS(IHR)=1.0
      IDIR=WD(IHR)
      IDPAST=WD(IHR) $ GO TO 185
 180  WS(IHR)=1.0 $ IDIR=IDPAST
C
C**********CALCULATING CONCENTRATION (GM/M*M*M) FROM FAR SOURCES.
C
 185  CFAR(NN)=PTFAR(IHR)*CFNORM(ISTAB,IDIR,J)*24.0/WS(IHR)
      IF (CLOSTYP.NE.6HSTREET) GO TO 190
C
C**********STREET USES A WIND SPEED = 0.5*(AIRPORT VALUE + 0.5 M/S)
C
      WS(IHR)=0.5*WS(IHR) + 0.25
C
C**********CALCULATING CONCENTRATION FROM NEAR SOURCES (GM/M*M*M).
C
 190  CNEAR(NN)=PTNEAR(IHR)*CNNORM(ISTAB,IDIR,J)*24.0/WS(IHR)
 195  CONTINUE
      GO TO 170
 200  NTOT=NN
C
C**********SET ARRAYS NEGATIVE...
C**********     TOP10= 10 HIGHEST MULTI-HOUR CONCENTRATIONS (MEANHR-AV-
C**********     ERAGE).
C**********     TOPRAT= RATIOS OF NEAR/FAR CONTRIBUTIONS ...SAME PERIODS
C**********     AS TOP10.
C**********     NHR= LAST HOUR OF AVERAGING PERIOD FOR EACH TOP10.
C
      CALL MEMSETX (-9.0,TOP10,10)
      CALL MEMSETX (-9.0,TOPRAT,10)
      CALL MEMSETX (-9,NHR,10)
C
C**********SET FREQUENCIES TO ZERO.
C
      CALL MEMSETX (0.0,FREQ,10)
      CALL MEMSETX (0.0,COFREQ,10)
C
C**********SET COUNTERS AND CONCENTRATION RUNNING SUMS TO ZERO.
C
      NN=MM=CLOSC=FARC=0.0
 205  NN=NN+1 $ MM=MM+1
      NMHP1 = NN-MEANHR+1
C
C**********SKIP INTERVALS WITH MISSING DATA.
C
      IF (CFAR(NN).GE.0.0.AND.CNEAR(NN).GE.0.0) GO TO 210
      MM=0 $ CLOSC=0.0 $ FARC=0.0 $ GO TO 205
C
C**********CALCULATE RUNNING SUMS.
C
 210  CLOSC=CLOSC+CNEAR(NN)
      FARC=FARC+CFAR(NN)
      IF (MM.LT.MEANHR) GO TO 205
      CTOT=CLOSC+FARC
      CALL CONFREQ
      IF (OUTPUT.EQ.5HWORST.OR.OUTPUT.EQ.4HBOTH) GO TO 215
      IF (OUTPUT.EQ.5HRATIO) GO TO 220
      PRINT 14
      STOP210
```

```
C
C**********CHECK TO SEE IF RUNNING SUM GREATER THAN THOSE ALREADY STORED
C
 215  IF (CTOT.GT.TOP10(10)) CALL BIG10
      IF (OUTPUT .EQ. 5HWORST) GO TO 222
C
C********** IF FARC=0 SET TO VERY SMALL NUMBER
C
 220  IF (FARC.LE.0.0) FARC=1.0E-20
      RATIO=CLOSC/FARC
      CALL RATFREQ
 222  CLOSC = CLOSC-CNEAR(NMHP1)
      FARC = FARC-CFAR(NMHP1)
      IF (NN.LT.NTOT) GO TO 205
      CALL CONPNT
      IF (OUTPUT.EQ.5HWORST.OR.OUTPUT.EQ.4HBOTH) 230,235
 230  CALL BIGPNT
      IF (OUTPUT.NE.4HBOTH) STOP230
 235  CALL RATPNT
      STOP235
      END
```

```
      SUBROUTINE BIGPNT
C
C**********THIS SUBPROGRAM PRINTS THE 10 LARGEST MEANHR-AVERAGES AND
C**********OTHER ITEMS.
C
      COMMON /TOP/ NN,CTOT,CLOSC,FARC,TOP10(10),NHR(10),TOPRAT(10),
     1COFREQ(10)
      COMMON /DAT/ ALPHA(16),MEANHR,CLOSTYP,NCLOSE
 1    FORMAT (1H1,5X16A5)
 2    FORMAT (/1H ,*HIGHEST*I3,  *-HOUR AVERAGES*)
 3    FORMAT (/1H ,*CLOSE = CONTRIBUTION FROM FIRST *I1,* SEGMENTS*)
 4    FORMAT (/1H ,*CLOSE = STREET CONTRIBUTION*)
 5    FORMAT (1X,  * RANK   DAY  HOUR*5X*CONCENTRATION*5X*RATIO*/1H ,18X
     1 *MG/M3*7X*PPM*5X*CLOSE/FAR*3X*TOP10*)
 6    FORMAT (1H ,3I5,3F10.2, 3X, E10.3)
 7    FORMAT (/1H ,13X,*LAST*)
      XMNHR = MEANHR
C
C**********PRINTING IDENTIFICATION AND HEADINGS.
C
      PRINT 1,ALPHA $ PRINT 2,MEANHR
      IF (CLOSTYP.EQ.6HSTREET) GO TO 100
      PRINT 3,NCLOSE $ GO TO 105
 100  PRINT 4
      PRINT 7
 105  PRINT 5
C
C**********CONVERTING UNITS AND AVERAGING AND PRINTING.
C**********      CMILGM=AVERAGE CONCENTRATION (E-3GM/M*M*M)
C**********      PPM=AVERAGE CONCENTRATION (PPM).
C**********      NDAY=NUMBER OF DAY IN WHICH LAST HOUR OF AVERAGING IN-
C**********      TERVAL OCCURS.
C**********      MHR=HOUR (OF NDAY) OF END OF AVERAGING INTERVAL.
C
      DO 110 I=1,10
      CMILGM=TOP10(I)*1.0E3/XMNHR
      PPM=CMILGM/1.2
      NDAY=NHR(I)/24+1
      MHR = MOD(NHR(I),24)
      IF (ABS(TOPRAT(I)) .GT. 1000.0) TOPRAT(I) = -99.99
      PRINT 6,I,NDAY,MHR,CMILGM,PPM,TOPRAT(I),TOP10(I)
 110  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BIG10
C
C**********THIS SUBPROGRAM CHECKS NN TO SEE IF IT IS WITHIN MEANHR OF
C**********ANY OF THE RETAINED VALUES OF NHR. IFNOT CTOT IS ADDED TO THE
C**********LIST OF RETAINED VALUES OF TOP10. TOP10(10) IS DROPPED AND TH
C**********LIST IS REORDERED,LARGEST (1) TO SMALLEST (10). NN AND
C**********CLOSC/FARC ARE ADDED TO THE NHR AND TOPRAT LISTS IN THE SAME
C**********POSITION THAT CTOT WAS ADDED TO THE TOP10 LIST. IF NN IS WITH
C**********IN MEANHR OF SOME NHR THEN THE LIST IS NOT REVISED UNLESS
C**********CTOT EXCEEDS THE CORRESPONDING TOP10.
C
      COMMON /TOP/ NN,CTOT,CLOSC,FARC,TOP10(10),NHR(10),TOPRAT(10),
     1COFREQ(10)
      COMMON /DAT/ ALPHA(16),MEANHR,CLOSTYP,NCLOSE
      RATSO = CLOSC/FARC
      DO 130 I=1,10
C
C**********CHECK TO SEE IF NN IS WITHIN MEANHR OF ANY NHR.
C
      IF ((NN-NHR(I)).GT. MEANHR) GO TO 130
C
C**********CHECK TO SEE IF CTOT IS GREATER THAN CORRESPONDING TOP10.
C
      IF (CTOT.GT.TOP10(I)) GO TO 120
      RETURN
C
C**********IF CTOT IS LARGER, MAKE SUBSTITIUTIONS.
C
 120  TOP10(I)=CTOT
      NHR(I)=NN
C
C********** IF FARC=0 REPLACE WITH VERY SMALL VALUE
C
      IF (FARC.LE.0.0) FARC=1.0E-20
      TOPRAT(I)=CLOSC/FARC
      GO TO 135
 130  CONTINUE
C
C
C**********IF NN IS NOT WITHIN MEANHR OF ANY NHR, SUBSTITUTE FOR 10TH
C**********ITEMS IN EACH LIST.
C********** IF FARC=0 REPLACE WITH VERY SMALL VALUE
C
      IF (FARC.LE.0.0) FARC=1.0E-20
      TOPRAT(10) = CLOSC/FARC
      TOP10(10) = CTOT
      NHR(10) = NN
 135  CONTINUE
C
C**********REORDER LISTS SO THAT TOP10 RUNS FROM LARGEST TO SMALLEST.
C
      DO 160 I=1,9
      J=I+1
 140  IF (TOP10(J).LE.TOP10(I)) GO TO 150
      TOPS=TOP10(I) $ TOP10(I)=TOP10(J) $ TOP10(J)=TOPS
      NHRS=NHR(I) $ NHR(I)=NHR(J) $ NHR(J)=NHRS
      TOPR=TOPRAT(I) $ TOPRAT(I)=TOPRAT(J) $ TOPRAT(J)=TOPR
 150  J=J+1
      IF (J.LE.10) GO TO 140
 160  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CONFREQ
C
C*********THIS SUBROUTINE ACCUMULATES FRQUENCIES OF TOTAL CALCULATED
C*********CONCENTRATIONS.
C**********    CLASSB=CLASS BOUNDARIES OF FREQUENCY DISTRIBUTION (MG/M3).
C**********    XXHR=AVERAGING INTERVAL (MEANHR).
C
      COMMON /CLS/ CLASSB(10)
      COMMON /DAT/ ALPHA(16),MEANHR,CLOSTYP,NCLOSE
      COMMON /TOP/ NN,CTOT,CLOSC,FARC,TOP10(10),NHR(10),TOPRAT(10),
     1COFREQ(10)
      DATA (CLASSB=0.0,0.5,1.0,2.0,4.0,8.0,12.0,16.0,32.0,64.0)
      XXHR = MEANHR
      COFREQ(1)=COFREQ(1)+1.0
C
C**********CONVERTING AVERAGE IN MG/M3 TO UNITS COMPARABLE TO SUMS.
C**********ACCUMULATING FREQUENCIES.
C
      DO 110 I=2,10
      CC = CLASSB(I)*XXHR*1.0E-3
      IF (CTOT .GT. CC) GO TO 100
      RETURN
 100  COFREQ(I)=COFREQ(I)+1.0
 110  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CONPNT
C
C*********THIS SUBROUTINE PRINTS FREQUENCY DISTRIBUTION OF CALCULATED
C*********CONCENTRATIONS AND OTHER RELATED INFORMATION.
C
      COMMON /CLS/ CLASSB(10)
      COMMON /TOP/ NN,CTOT,CLOSC,FARC,TOP10(10),NHR(10),TOPRAT(10),
     1COFREQ(10)
      COMMON /DAT/ ALPHA(16),MEANHR,CLOSTYP,NCLOSE
 1    FORMAT (1H1,15X16A5)
 2    FORMAT (/1H ,I5,*-HOUR AVERAGES*)
 3    FORMAT (/,1H ,*ALL AREA SOURCES*)
 4    FORMAT (/,1H ,*CLOSE SOURCE IS STREET*)
 5    FORMAT (/,1H ,10X*CONCENTRATIONS GREATER THAN (MG/M3)...*)
 6    FORMAT (/,1H ,9X10F10.3)
 7    FORMAT (/,1H ,*NUMBER = *10F10.0)
 8    FORMAT (/,1H ,*PERCENT =*10F10.2)
C
C**********PRINTING HEADINGS.
C
      PRINT1,ALPHA
      PRINT 2,MEANHR
      IF (CLOSTYP.EQ.6HSTREET) GO TO 100
      PRINT 3 $ GO TO 110
 100  PRINT 4
 110  PRINT 5
C
C**********PRINTING NUMERICAL FREQUENCIES.
C
      PRINT 6,CLASSB
      PRINT 7,COFREQ
C
C**********NORMALIZING TO PERCENTAGES.
C
      PERCENT=0.01*COFREQ(1)
      DO 120 I=1,10
      COFREQ(I)=COFREQ(I)/PERCENT
 120  CONTINUE
C
C**********PRINTING PERCENTAGE FREQUENCIES.
C
      PRINT 8,COFREQ
      RETURN
      END
```

```
      SUBROUTINE RATFREQ
C
C***********THIS SUBPROGRAM ACCUMULATES THE FREQUENCY DISTRIBUTION OF THE
C***********RATIOS OF THE NEAR/FAR SOURCES (RATIO).
C
      COMMON /RAT/ RATIO,FREQ(10),VALUE(10)
C
C***********VALUE=CLASS BOUNDARIES FOR CUMULATIVE FREQUENCY DISTRIBUTION
C***********(NUMBER GREATER THAN...)
C
      DATA (VALUE=0.0,0.02,0.04,0.08,0.2,0.4,0.8,2.0,4.0,8.0)
      FREQ(1)=FREQ(1)+1.0
      DO 110 I=2,10
      IF (RATIO.GE.VALUE(I)) GO TO 100
      RETURN
 100  FREQ(I)=FREQ(I)+1.0
 110  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RATPNT
C
C**********THIS SUBPROGRAM PRINTS CUMULATIVE FREQUENCY DISTRIBUTIONS FOR
C**********RATIOS OF NEAR/FAR CONTRIBUTION TO CONCENTRATION.
C
      COMMON /DAT/ ALPHA(16),MEANHR,CLOSTYP,NCLOSE
      COMMON /RAT/ RATIO,FREQ(10),VALUE(10)
 1    FORMAT (1H1,15X16A5)
 2    FORMAT (/1H ,*RATIOS BASED ON*I3,*-HOUR AVERAGE*)
 3    FORMAT (/1H ,*CLOSE = CONTRIBUTION FROM FIRST *I1,* SEGMENTS*)
 4    FORMAT (/1H ,*CLOSE = STREET CONTRIBUTIONS*)
 5    FORMAT (/1H ,10X*RATIO OF CLOSE/FAR CONTRIBUTIONS GREATER THAN...*
     1)
 6    FORMAT (/1H ,9X10F10.3)
 7    FORMAT (/1H ,*NUMBER  =*10F10.1)
 8    FORMAT (/1H ,*PERCENT =*10F10.2)
 9    FORMAT (1H1,*NO VALID DATA*)
C
C**********PRINTING IDENTIFICATION AND HEADINGS.
C
      PRINT 1,ALPHA $ PRINT 2,MEANHR
      IF (CLOSTYP.EQ.6HSTREET) GO TO 100
      PRINT 3,NCLOSE $ GO TO 110
 100  PRINT 4
 110  PRINT 5
C
C**********PRINTING NUMERICAL FREQUENCIES.
C
      PRINT 6,VALUE $ PRINT 7,FREQ
      IF(FREQ(1) .LE. 0.0) 112, 116
  112 PRINT 9 $ RETURN
C
C**********NORMALIZING TO PERCENTAGES.
C
  116 PERCENT= 100.0/FREQ(1)
      DO 120 I=1,10
      FREQ(I)=FREQ(I)*PERCENT
 120  CONTINUE
C
C**********PRINTING PERCENTAGE FREQUENCIES.
C
      PRINT 8,FREQ
      RETURN
      END
```

```
      SUBROUTINE STREET
C
C***********THIS SUBPROGRAM CALCULATES STREET CONTRIBUTION TO CONCENTRA-
C***********TION FOR UNIT WIND SPEED....
C***********     QST=EMISSION RATE ON STREET (GM/M*S).
C***********     IDIR=WIND DIRECTION (16 POINT).
C***********     STDIR=STREET DIRECTION (DEGREES CW FROM NORTH).
C***********     SIDE (LEFT OR RIGHT)= SIDE OF RECEPTOR WHEN FACING STDIR
C***********     W,H=WIDTH AND HEIGHT OF STREET CANYON (M).
C***********     Z,X=HEIGHT AND HORIZONTAL DISTANCE OF RECEPTOR FROM TRAF
C***********     FIC.
C***********     COS60=COSINE(60 DEGREES).
C
      COMMON /VAR/ XNORM,QST,SIDE,IDIR,STDIR,W,H,Z,X
      DATA COS60 /0.5/
C
C***********ANGLE NORMAL TO STDIR.
C
      IF (SIDE.NE.4HLEFT) GO TO 100
      ANGLE=STDIR-90.0
      GO TO 120
  100 IF (SIDE.EQ.5HRIGHT) GO TO 110
      PRINT 1 $ STOP100
    1 FORMAT (/1H ,*BAD STREET SIDE DESIGNATION*)
  110 ANGLE=STDIR+90.0
C
C***********CONVERTING WIND DIRECTION TO DEGREES.
C
  120 WD=IDIR $ WD=22.5*(WD-1.0)
C
C***********COSINE OF DIFFERENCE BETWEEN WIND DIR AND NORMAL TO ST.DIR.
C
      COSDIF=COS((WD-ANGLE)*0.0174533)
C
C***********CWIND (CLEE)=CONCENTRATION WITH UNIT WIND SPEED FOR RECEPTOR
C***********FACING TOWARD (AWAY FROM) THE WIND DIRECTION.
C
      CWIND=7.0*QST*(H-Z)/(1.5*W*H)
      CLEE =7.0*QST/(1.5*(SQRT(X*X+Z*Z)+2.0))
C
C***********TESTS TO DETERMINE WHETHER THE WIND IS BLOWING WITHIN 30 DE-
C***********GREES OF STDIR, OR TOWARD, OR AWAY FROM RECEPTOR.
C
      IF (COSDIF.GT.0.0) GO TO 125
      IF (ABS(COSDIF).LE.COS60) GO TO 130
      XNORM=CWIND
      RETURN
  125 IF (ABS(COSDIF).LE.COS60) GO TO 130
      XNORM=CLEE
      RETURN
  130 XNORM=(CLEE+CWIND)*0.5
      RETURN
      END
```

Appendix B

SOURCES OF TRAFFIC INFORMATION

Appendix B

SOURCES OF TRAFFIC INFORMATION

Traffic information is generally available in urban areas where it is collected for use in traffic control. In small towns and outlying areas, data may not always be available, but a check with the local highway, transportation, or public works offices would reveal any special counts that may have been taken. State and federal highway counts are maintained and updated regularly. The U.S. Department of Transportation, Federal Highway Administration, publishes a directory, "Urbanized Area Transportation Planning Programs," that lists traffic agencies throughout the country, as well as key officials of these agencies. The directory is divided into four sections:

- Section I: Lists the metropolitan area transportation planning programs.
- Section II: Lists the Federal Highway Administration regional planning engineers.
- Section III: Lists the Federal Highway Administration Division planning and research engineers.
- Section IV: Lists the State Highway Department planning engineers.

Copies may be obtained from the Federal Highway Administration, 400 Seventh Street, S. W., Washington, D.C., 20590.

Traffic information may appear in many forms. Examples are shown in Table B-1 and Figures B-1 through B-5. Table B-1 gives traffic volumes at different locations along a state (California) highway. The traffic during peak hours, the average daily traffic (ADT) during the peak month, and for the whole year are all given. The highway segments are identified by name and mile-post values.

Figure B-1 shows a street map of Washington, D.C., drawn so that the street widths are proportional to traffic volumes. Figure B-2 is an example of the same graphic technique applied over a larger area (northwestern Virginia). Figure B-3 illustrates another, simpler method of designating traffic volumes along a road network.

Figure B-4 shows traffic volumes that are presented in still another way. In this instance, the average daily traffic on all of the streets in each of the squares have been used to determine the average total number of vehicle miles traveled on surface streets each day, in

Table B-1

EXAMPLE OF TABULATED TRAFFIC VOLUMES

1971 TRAFFIC VOLUMES

Rte 101, SM Co

Milepost	Description	Peak Hour	ADT Pk. Mo.	ADT Annual
5.39	Redwood City, Jct. Rte. 114, Chestnut-Spruce Street Interchange			
		9,700	110,000	102,000
6.62	Redwood City, Whipple Avenue Interchange			
		10,500	119,000	111,000
8.40	Holly Street Interchange			
		11,200	127,000	118,000
9.55	Belmont, Ralston Avenue Interchange			
		11,600	132,000	122,000
11.15	San Mateo, Hillsdale Boulevard Interchange			
		12,100	137,000	127,000
11.90	San Mateo, Jct. Rte. 92, 19th Avenue Interchange			
		12,800	146,000	135,000
12.69	San Mateo, Kehoe Avenue Connection			
		12,800	146,000	135,000
13.46	San Mateo, Third Avenue Interchange			
		13,100	149,000	138,000
14.33	San Mateo, Poplar-Dore Avenue Connections			
		12,700	144,000	134,000
14.69	San Mateo, Peninsular Avenue Interchange			
		12,700	144,000	134,000
16.58	Burlingame, Broadway Interchange			
		12,600	143,000	133,000
17.95	Millbrae, Millbrae Avenue Interchange			
		13,000	147,000	137,000
19.12	San Francisco Airport Interchange			
		13,400	153,000	141,000
20.40	San Bruno Avenue Interchange			
21.45	South San Francisco, South Airport Boulevard Interchange	11,300	129,000	119,000
		11,100	126,000	117,000
21.92	South San Francisco, Grand Avenue Interchange			
		11,700	132,000	123,000
22.55	South San Francisco, Linden Avenue Connection			
22.71	South San Francisco, Oyster Point Boulevard Interchange	11,000	125,000	116,000
23.39	South San Francisco, Old Bayshore Connection (Sierra Point)	11,400	129,000	120,000

Rte 101, Mrn Co

Milepost	Description	Peak Hour	ADT Pk. Mo.	ADT Annual
23.39	South San Francisco, Old Bayshore Connection (Sierra Point)			
		11,200	127,000	118,000
25.70	Brisbane, Candlestick Park Connections			
25.11	San Mateo County (Brisbane North City Limits)			
=0.00	San Francisco County (San Francisco South City Limits)	11,200	127,000	118,000
0.77	San Francisco, Third Street Interchange			
		11,200	128,000	118,000
1.11	San Francisco, Paul Avenue Connection			
		11,300	128,000	119,000
1.77	San Francisco, Silver Avenue Interchange			
1.98	San Francisco, Jct. Rte. 280, Alemany Boulevard Interchange	12,100	137,000	127,000
		15,000	199,000	185,000
2.92	San Francisco, Army Street Interchange			
		15,000	206,000	191,000
4.10	San Francisco, Vermont Street Connection			
		15,000	201,000	186,000
R4.24	San Francisco, Jct. Rte. 80 Eastbound Lanes			
		10,000	120,000	111,000
R5.14	San Francisco, Mission Street-South Van Ness Avenue Connections			
		8,100	97,000	90,000
R5.47 =4.54	San Francisco, Market Street			
4.76	San Francisco, Oak-Fell Street Connections	8,500	96,000	89,000
5.09	End Freeway			
		4,550	52,000	48,000
5.17	San Francisco, Turk Street-Golden Gate Avenue Connections. End Freeway			
		4,700	53,000	49,500
5.35	San Francisco, Turk Street			
		5,000	62,000	53,000
5.94	San Francisco, California Street	4,450	55,000	47,000
		4,100	50,000	43,000
6.71	San Francisco, Jct. Rte. 480, Lombard Street	4,100	50,000	43,000
	(Break in Route)			
	Marin County			
0.00	North End Golden Gate Bridge. Begin Freeway			

147570 441

Source: California Division of Highways

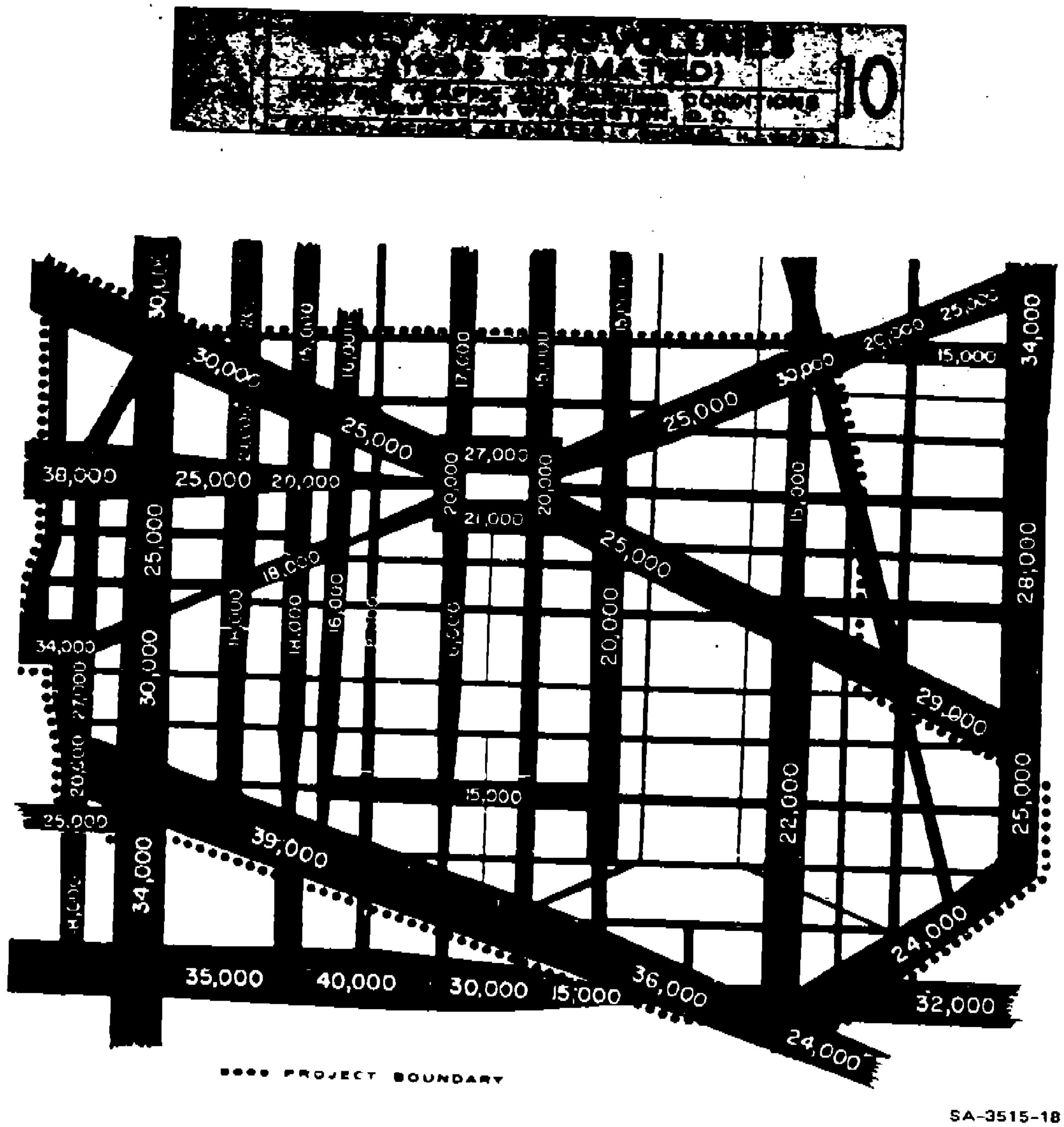
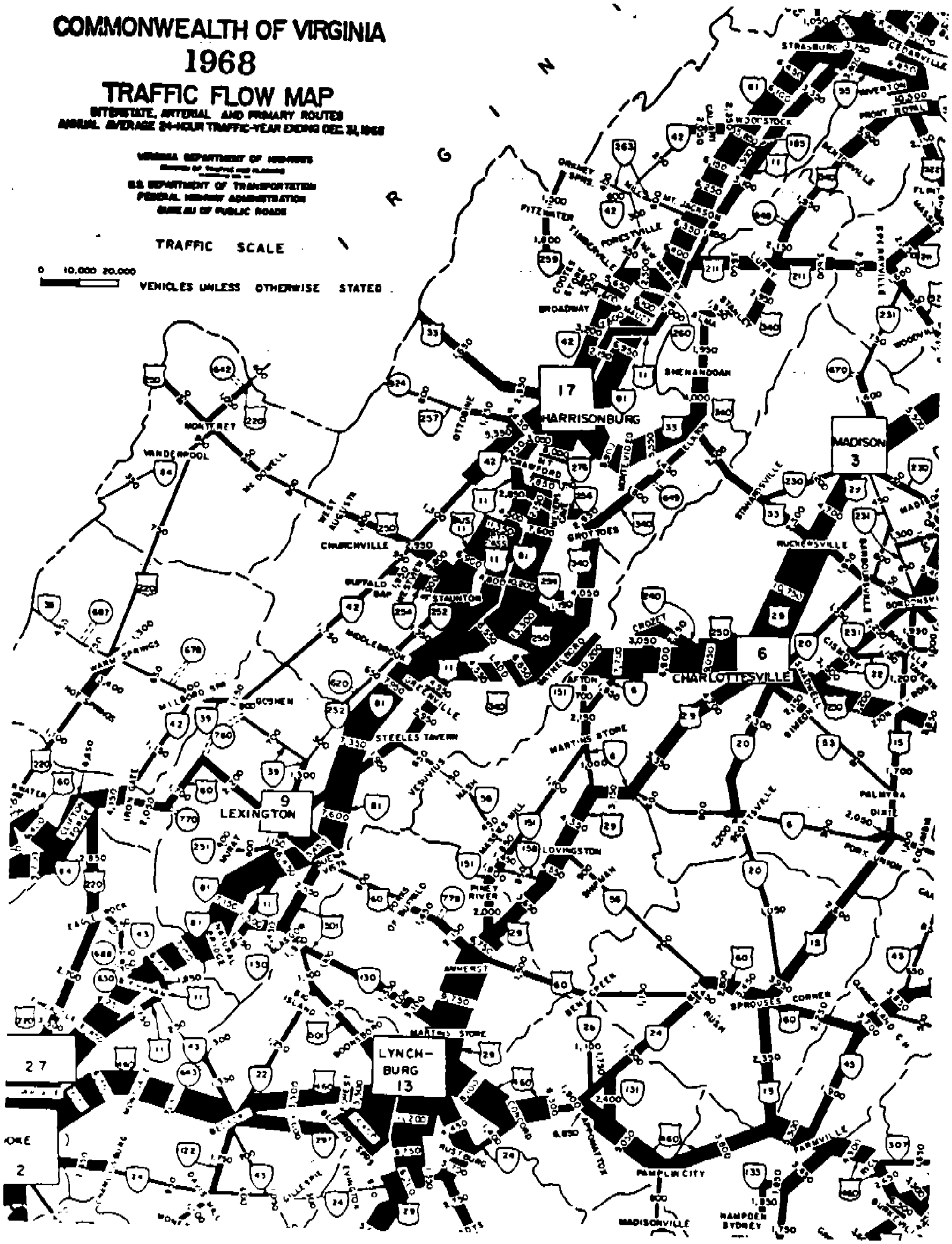
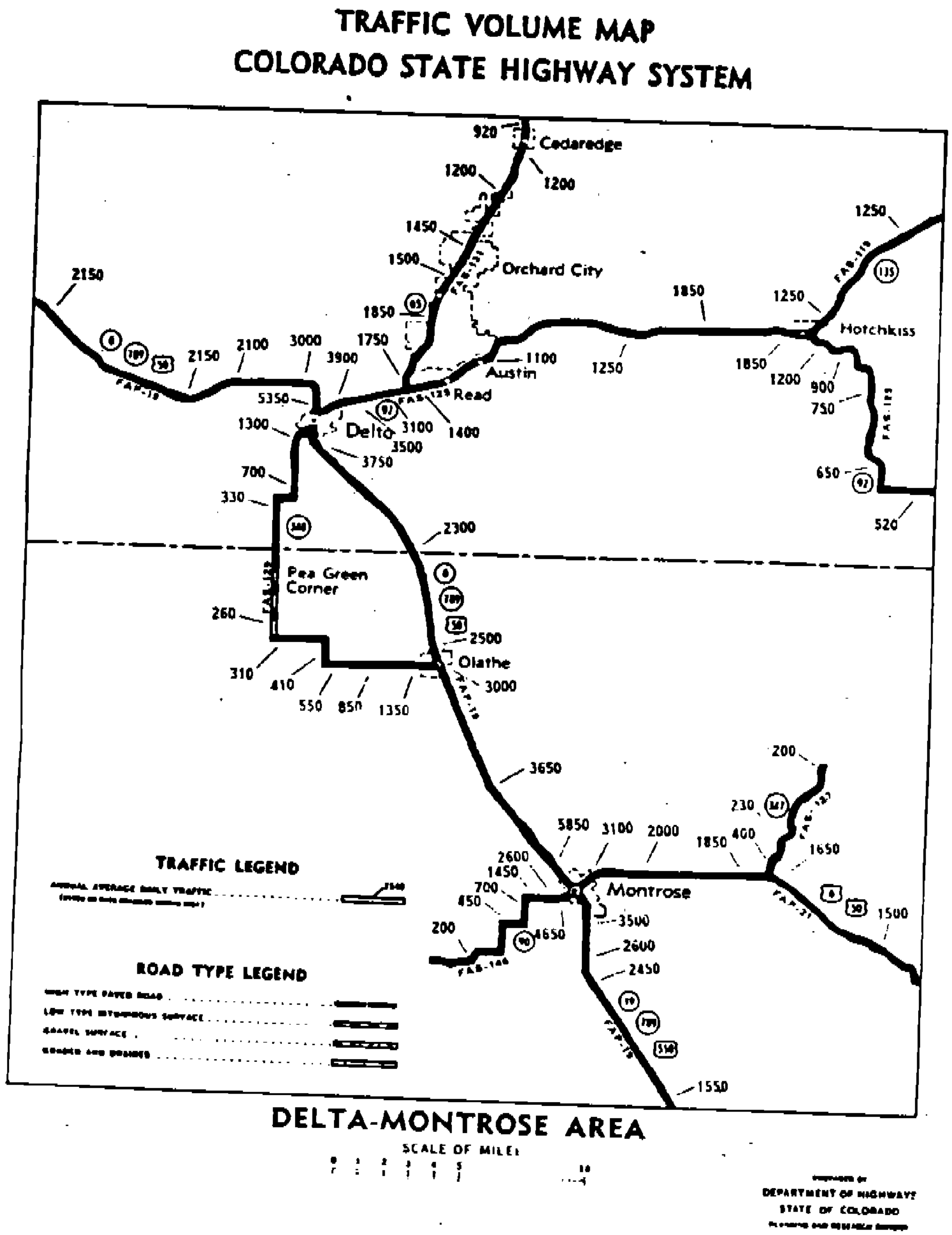


FIGURE B-1 SAMPLE TRAFFIC MAP FOR A DOWNTOWN AREA



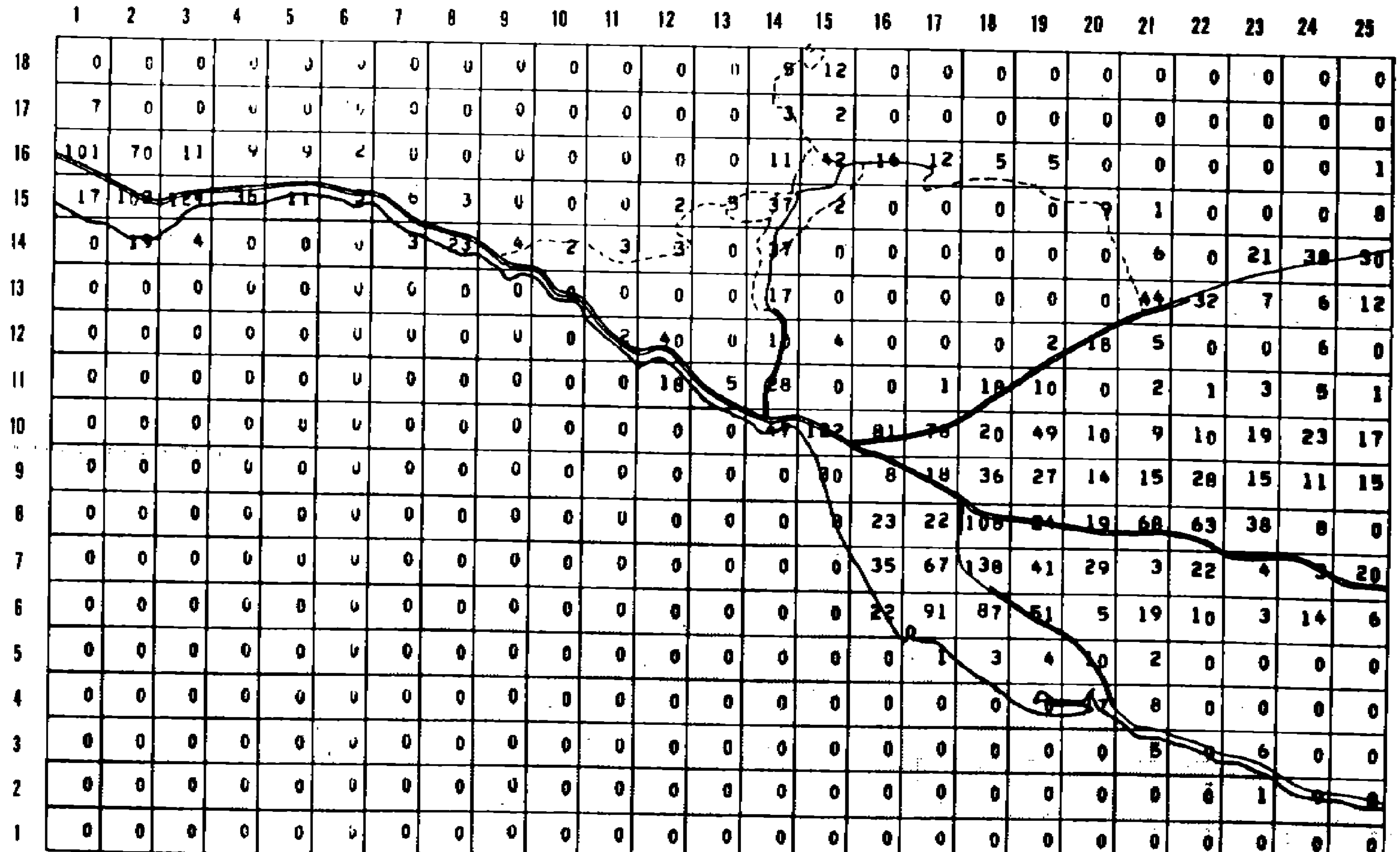
SA-3515-19

FIGURE B-2 SAMPLE TRAFFIC MAP FOR AN INTERCITY AREA, VIRGINIA



SA-3515-20

FIGURE B-3 SAMPLE TRAFFIC MAP FOR AN INTERCITY AREA, COLORADO



SOURCE: Ludwig et al. 1975

SA-3515-25

FIGURE B-4 SAMPLE OF GRIDDED TRAFFIC DATA that 2-mile square. This type of traffic data is not as common as the others, but such inventories are known to have been made for at least three areas in California: the Los Angeles Basin (Roberts et al, 1971), the San Francisco Bay Area (Ludwig and Kealoha, 1974), and the example shown in Figure B-4, Ventura County (Ludwig et al, 1975).

In the late-1960s, a series of documents was prepared for many U.S. urban areas by the U.S. Department of Health, Education, and Welfare. The generic title of these documents is:

> "Report for Consultation on the Metropolitan. . . Air Quality Control Region"

The missing words in the title give the name of the appropriate intrastate or interstate metropolitan area. Some of these documents contained gridded estimates of daily average CO emission rates. Since most CO is emitted from vehicular sources, these inventories will be closely related to traffic, and could be used as data for such estimations, if no better information were available.

Appendix C

SOURCES OF CLIMATOLOGICAL AND METEOROLOGICAL INFORMATION

Appendix C

SOURCES OF CLIMATOLOGICAL AND METEOROLOGICAL INFORMATION

One of the most helpful publications specifically designed to assist potential users of climatological data is called "Selective Guide to Climatic Data Sources," Key to Meteorological Records Documentation Number 4.11, prepared by the staff at the National Climatic Center, Ashville, N.C., for sale by the Government Printing Office, Washington, D.C. Its format indicates the publication(s) in which various climatological categories (temperature, precipitation, wind, humidity, and so on) may be found. Although this publication refers primarily to published climatological data, a wealth of unpublished climatological summaries are also available on special order from the files of the National Climatic Center An index to the summaries that can be ordered is given in the "Guide to Standard Weather Summaries," NAVAIR 50-IC-534, U.S. Navy, March 1968.

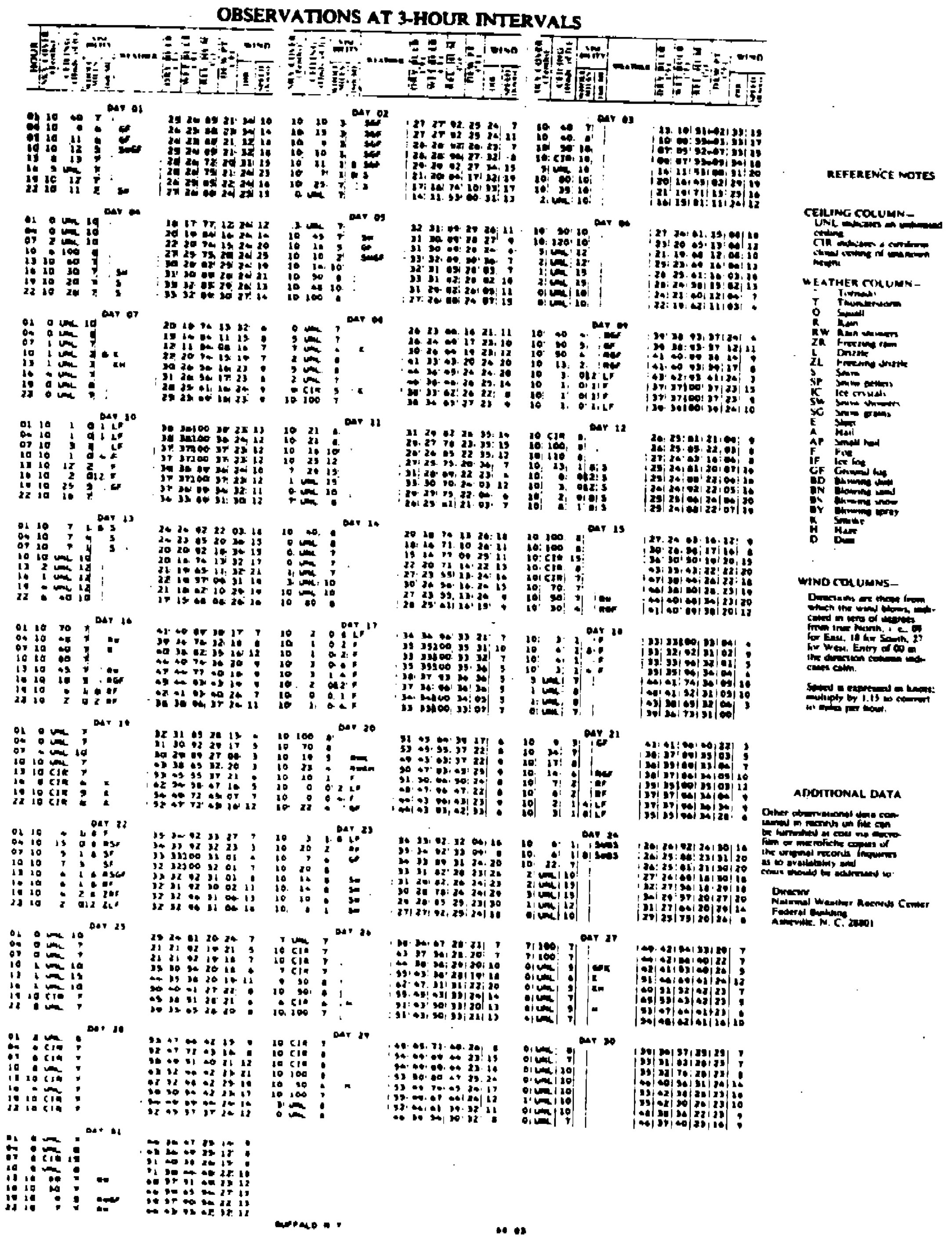
The National Climatic Center makes every effort to obtain a copy of all meteorological records collected in the United States. These data are available and can be ordered on microfilm, magnetic tape, hard copies, or as copies of raw data. The address and phone number are:

Director, National Climatic Center
Federal Building
Ashville, North Carolina 28801
Telephone: (704) 258-2850

The Center answers inquiries and analyzes, evaluates, and interprets data. Routine letters or telephone inquires are usually answered without charge; other services are provided at cost.

The bulk of the data at the Climatic Center are meteorological observations made at airfields by the National Weather Service, the Federal Aviation Administration, and the Defense Department. Figure C-1 shows an example of the kind of information to be found on a three-hourly tabulation for one month at one station. Climatic information is seldom available to the extent that it will be desired, but ingenuity can often be used to ferret out sources not generally available from the usual public data repositories.

At the State and regional level, fire stations, highway and transportation departments, environmental studies groups, air pollution districts, and utility districts may have continuing meteorological records or special weather studies available. A call directly to these agencies may result in a data source not available anywhere else.



OBSERVATIONS AT 3-HOUR INTERVALS

REFERENCE NOTES

CEILING COLUMN—
UNL indicates an unlimited ceiling.
CIR indicates a cirriform cloud ceiling of unknown height.

WEATHER COLUMN—
- Tornado
T Thunderstorm
Q Squall
R Rain
RW Rain showers
ZR Freezing rain
L Drizzle
ZL Freezing drizzle
S Snow
SP Snow pellets
IC Ice crystals
SW Snow showers
SG Snow grains
E Sleet
A Hail
AP Small hail
F Fog
IF Ice fog
GF Ground fog
BD Blowing dust
BN Blowing sand
BS Blowing snow
BY Blowing spray
K Smoke
H Haze
D Dust

WIND COLUMNS—
Directions are those from which the wind blows, indicated in tens of degrees from true North, i. e., 09 for East, 18 for South, 27 for West. Entry of 00 in the direction column indicates calm.

Speed is expressed in knots; multiply by 1.15 to convert to miles per hour.

ADDITIONAL DATA

Other observational data contained in records on file can be furnished at cost via microfilm or microfiche copies of the original records. Inquiries as to availability and costs should be addressed to:

Director
National Weather Records Center
Federal Building
Asheville, N. C. 28801

SA-3515-26

FIGURE C-1 EXAMPLE OF METEOROLOCICAL RECORDS AVAILABLE FROM THE NATIONAL CLIMATIC CENTER

Schools, colleges, industrial complexes (such as oil refineries), agricultural research stations, radio-TV stations, and electrical power plants may cooperate with a data collection program if asked.

The following publications provide important information concerning useful data sources.

1. Air Pollution Control Association (1973-1974): "Directory, Governmental Air Pollution Agencies", published in cooperation with the Office of Air Programs, EPA. This directory lists federal, state, regional, and county agencies conducting air pollution programs. Names of officials, titles, addresses, and telephone numbers are given. Write to W. T. Beery, Editor, Directory Governmental Air Pollution Agencies, Air Pollution Control Association, 4400 Fifth Avenue, Pittsburg, PA 15213.

2. World Weather Records, Smithsonian Misc. Collections, Vol. 79, Publication 2913, Assembled and arranged for publication by H. H. Clayton, published by the Smithsonian Institution, August 1927. This reference book contains monthly and annual means of pressure, temperature, and totals of rainfall.

A more extensive collection consisting of climatological data for selected airfields and for the climatic areas in which they are located has been compiled by the USAF Environmental Technical Applications Center (ETAC), Building 159, Navy Yard Annex, Washington, D.C. 20333. This series is also being published by the U.S. Naval Weather Service, Navy Yard, Washington, D.C. 20390, under the title "U.S. Naval Weather Service World-Wide Airfield Summaries." Table C-1 lists the available volumes in this series. Volume VIII contains summaries for the United States. Information requests should be addressed to:

The National Technical Information Service (NTIS)
Springfield, Virginia 22151.

3. "The Climatic Atlas of the United States," (1968) is a comprehensive series of monthly and annual analyses showing the national distribution of mean, normal and/or extreme values of temperature, precipitation, wind, pressure, relative humidity, dewpoint, sunshine, sky cover, heating degree days, solar adiation and evaporation. It was prepared by the Environmental Data Service, NOAA, U.S. Department of Commerce, for sale by the Superintendent of Documents, Washington, D.C.

4. "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States" by George C. Holzworth illustrates seasonal and annual, morning and afternoon mean mixing heights, wind speeds, and normalized pollutant concentrations that were exceeded 10, 25, and 50 percent of the time for specified city sizes. Copies of this report (Office of Air Programs Publication No. AP-101) may be ordered from the Office of Technical Information and Publications, Office of Air Programs, Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

Table C-1

PUBLISHED VOLUMES OF WORLD-WIDE AIRFIELD SUMMARIES

Published volumes of World-wide Airfield Summaries are available for the following areas:

Volume		Name	NTIS Accession Number
Volume I		Southeast Asia (Revised)	AD-706-355
Volume II (Parts 1 & 2)		Middle East	AD-662-425 & AD-662-427
Volume III		Far East	AD-662-426
Volume IV		Canada-Greenland-Iceland	AD-662-424
Volume V		Australia-Antarctica (including So. Pacific Is.)	AD-662-648
Volume VI (Parts 1 & 2)		South America	AD-664-828 & AD-664-829
Volume VII		Central America	AD-671-845
Volume VIII		United States of America	
	Part 1	West Coast, Western Mtns. and Great Basin	AD-688-472
	Part 2	Rocky Mtns. and Northwest Basin	AD-689-792
	Part 3	Central Plains	AD-693-491
	Part 4	Great Lakes	AD-696-971
	Part 5	Mississippi Valley	AD-699-917
	Part 6	Southeastern Region	AD-701-719
	Part 7	East Coast and Appalachian Region	AD-703-606
	Part 8	Alaska and Hawaii	AD-704-607
Volume IX		Africa	
	Part 1	Northern Half	AD-682-915
	Part 2	Southern Half	AD-682-915
Volume X		Europe	
	Part 1	Scandinavia & Northern Europe	
	Part 2	Low Countries & British Isles	
	Part 3	Alps & Southwest Europe	
	Part 4	Mediterranean	

Source: USAF Environmental Technical Applications Center, 1971

The National Climatic Center will prepare special data summaries. They also have standard computer programs available for special summaries. One of the most useful summaries for air pollution studies is that prepared by the STAR program. It is a joint frequency distribution of atmospheric stability and wind speed and direction. The atmospheric stability is calculated objectively from the cloud cover and wind data. This stability algorithm is based on the work of Pasquill (1961). The summaries can be based on any extended period of record with separate outputs for the months or seasons, as well as an annual summary. There are some pollution models that use the output of STAR program as part of their input requirements.

Appendix D

SOURCES OF LAND USE INFORMATION

Appendix D

SOURCES OF LAND USE INFORMATION

The extent and availability of land use data is dependent on the specific area under study and what one chooses to call "land use information." The more formal information can be obtained at different levels of government. Some states have developed sizable data bases as an aid in generalized state planning (i.e., Connecticut, Florida, Hawaii, Maine, Vermont). The majority of states, however, are just beginning the information gathering process. Land use information for nonurban areas is best obtained from State Planning and regional agencies.

Regional planning agencies (e.g., the Denver Council of Governments in Colorado, Southeastern Virginia, Planning District Commission, and the Comprehensive Planning Organization in San Diego) can be excellent sources of information. These regional agencies gather socioeconomic, existing land use, and transportation data. Comprehensive regional plans can then be prepared to provide projections of long range demographic growth and land use.

Cities and counties will usually have current, readily available data on population, employment, existing and projected land use, general development plans and zoning regulations. Also, they will be able to provide basic transportation information and maps of major arterials and proposed thoroughfares.

In cities with schools of urban and regional planning, planning professors can help the researcher meet specific needs. Also, their libraries can be researched for applicable graduate and doctoral theses which are frequently case studies of the immediate vicinity.

There are other sources of land use information that are not specifically directed to the topic. Good maps or aerial photographs can provide a lot of useful information that may not be available from conventional land use sources. Useful sources of information for the United States are discussed next.

A. U.S. Bureau of the Census

Demographic and socioeconomic information of use to planners is available from the Department of the Census. Data developed by census tracts can be used to answer questions regarding a neighborhood's population and characteristics. Census tract information can be outdated, so it should be supplemented by material developed by the city, county, or regional planning bodies.

B. United States Geological Survey (USGS)

1. Topographic Maps

Topographic maps portray man-made and natural features, and the shape and elevation of the terrain. The usefulness of topographic maps is revealed in their accuracy, availability, economy, and wealth of detail. All maps are classified according to scale. The map scale expresses a ratio between the features shown on the map and the same features on the earth's surface. A scale of 1:24,000 states that one unit on the map represents 24,000 units on the ground. Figure D-1 is an example of three map scales of the same area showing the type of information that is available in large, medium, and small scale maps. Table D-1 is a summary of the principal maps and their essential characteristics. A booklet describing topographic maps and symbols is available free upon request from the Geological Survey. To order maps of a specific area, first obtain a state index map by asking for the "Index to Topographic Maps of (state)." An order form is included with each index as well as a list of local merchants that may stock topographic maps. Map reference facilities are also maintained in many public libraries. All maps for areas west of the Mississippi may be purchased by mail or over the counter from: Distribution Section, U.S. Geological Survey, Federal Center, Denver, Colorado, 80225; and for areas east of the Mississippi: distribution Section USGS, 1200 S. Eads Street, Arlington, Virginia 33303.

2. Photoimage Maps

Photoimage maps are available in the 1:24,000 scale. These are a new standard product called the orthophotoquad maps. An orthophotoquad portrays by aerial photoimagery a wealth of detail not found in conventional line maps. Yet there is the same positional accuracy as in standard topographic maps. Orthophotoquads are reproduced in black and white as photographic, diazo, or lithograpic copies. Diazo or lithographic products are comparable in price with 7.5 minute topographic maps. To obtain an index of orthophotoquad availability, contact the:

National Cartographic Information Center
U. S. Geological Survey
National Center, Stop 507
Reston, Virginia 22092
(703) 860-6045

Figure D-2 shows a portion of the orthophotoquad index, legend, and a coded portion of the state of Florida (USGS, 1974).

Table D-1

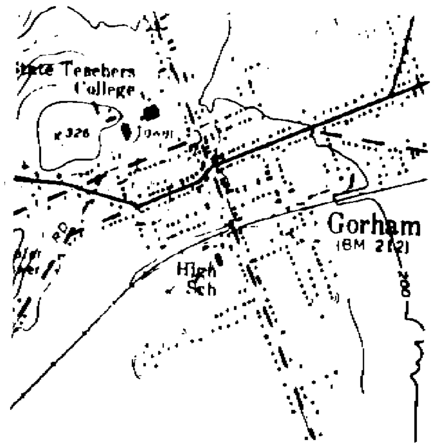
NATIONAL TOPOGRAPHIC MAPS

Series	Scale	1 inch represents	Standard quadrangle size (latitude-longitude)	Quadrangle area (square miles)	Paper size E-W N-S width length (inches)
$7\frac{1}{2}$-minute	1:24,000	2,000 feet	$7\frac{1}{2} \times 7\frac{1}{2}$ min.	49 to 70	[1] 22×27
Puerto Rico $7\frac{1}{2}$-minute	1:20,000	about 1,667 feet	$7\frac{1}{2} \times 7\frac{1}{2}$ min.	71	$29\frac{1}{2} \times 32\frac{1}{2}$
15-minute	1:62,500	nearly 1 mile	15×15 min.	197 to 282	[1] 17×21
Alaska 1:63,360	1:63,360	1 mile	15×20 to 36 min.	207 to 281	[2] 18×21
U.S. 1:250,000	1:250,000	nearly 4 miles	[3] $1° \times 2°$	4,580 to 8,669	[4] 34×22
U.S. 1:1,000,000	1:1,000,000	nearly 16 miles	[3] $4° \times 6°$	73,734 to 102,759	27×27

[1] South of latitude 31 $7\frac{1}{2}$-minute sheets are 23×27 inches; 15-minute sheets are 18×21 inches.
[2] South of latitude 62 sheets are 17×21 inches.
[3] Maps of Alaska and Hawaii vary from these standards.
[4] North of latitude 42 sheets are 29×22 inches. Alaska sheets are 30×23 inches.

Source: USGS, 1969

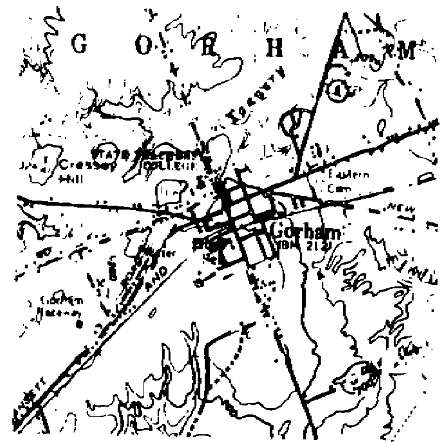
1:24,000 scale,
1 inch = 2000 feet
Area shown,
1 square mile



LARGE SCALE

SOURCE: USGS, 1969.

1:62,500 scale,
1 inch = nearly 1 mile
Area shown,
6-3/4 square miles



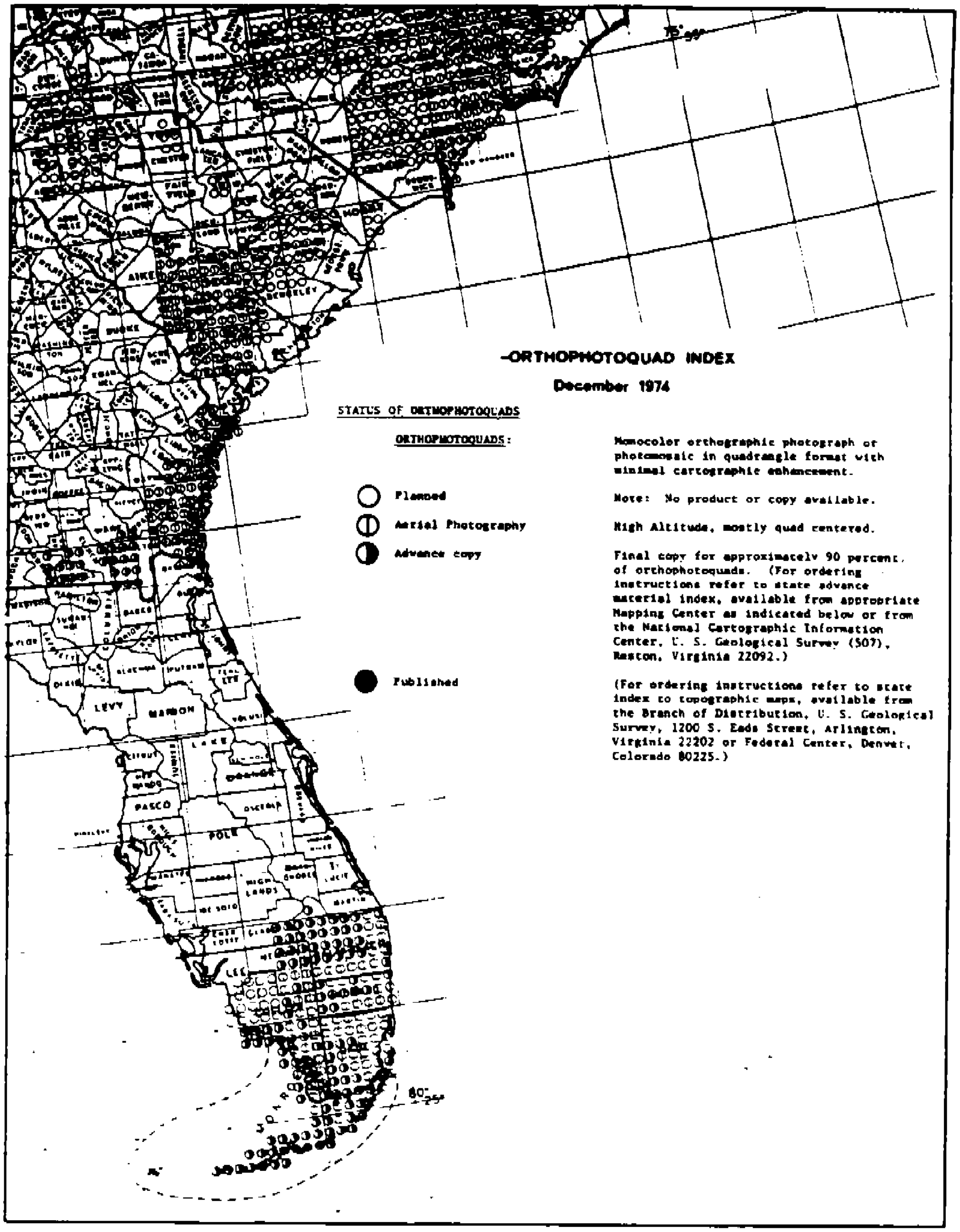
MEDIUM SCALE

1:250,000 scale,
1 inch = nearly 4 miles
Area shown,
107 square miles

SMALL SCALE

SA-3515-21

FIGURE D-1 AN EXAMPLE OF THE INFORMATIONAL CONTENT OF THE LARGE, MEDIUM, AND SMALL SCALE TOPOGRAPHIC MAP



SA-3515-22

FIGURE D-2 A PORTION OF THE ORTHOPHOTOQUAD INDEX SHOWING THE LEGEND AND A PORTION OF THE STATE OF FLORIDA

3. Earth Resources Technology Satellite

The Earth Resources Technology Satellite (ERTS) has the multispectral sensors on board that "photograph" the earth's surface in the visible through near-infrared range. The potential of such a capability for land use mapping, updating, and projection is currently a subject of extensive study. The images received from the satellite are available for sale as individual frames each covering an area approximately 1000 x 100 nautical miles with a 10 percent overlap along the spacecraft track.

Table D-2

PICTURE PRODUCTS AVAILABLE FROM ERTS

Image Size	Scale	Material
70mm (contact size)	1:3,369,000	Resin coated paper, film positive or negative
7 1/2" x 7 1/2"	1:1,000,000	Resin coated paper
15" x 15"	1:500,000	Resin coated paper
30" x 30"	1:250,000	Resin coated paper

Source: EDCDM Form 6

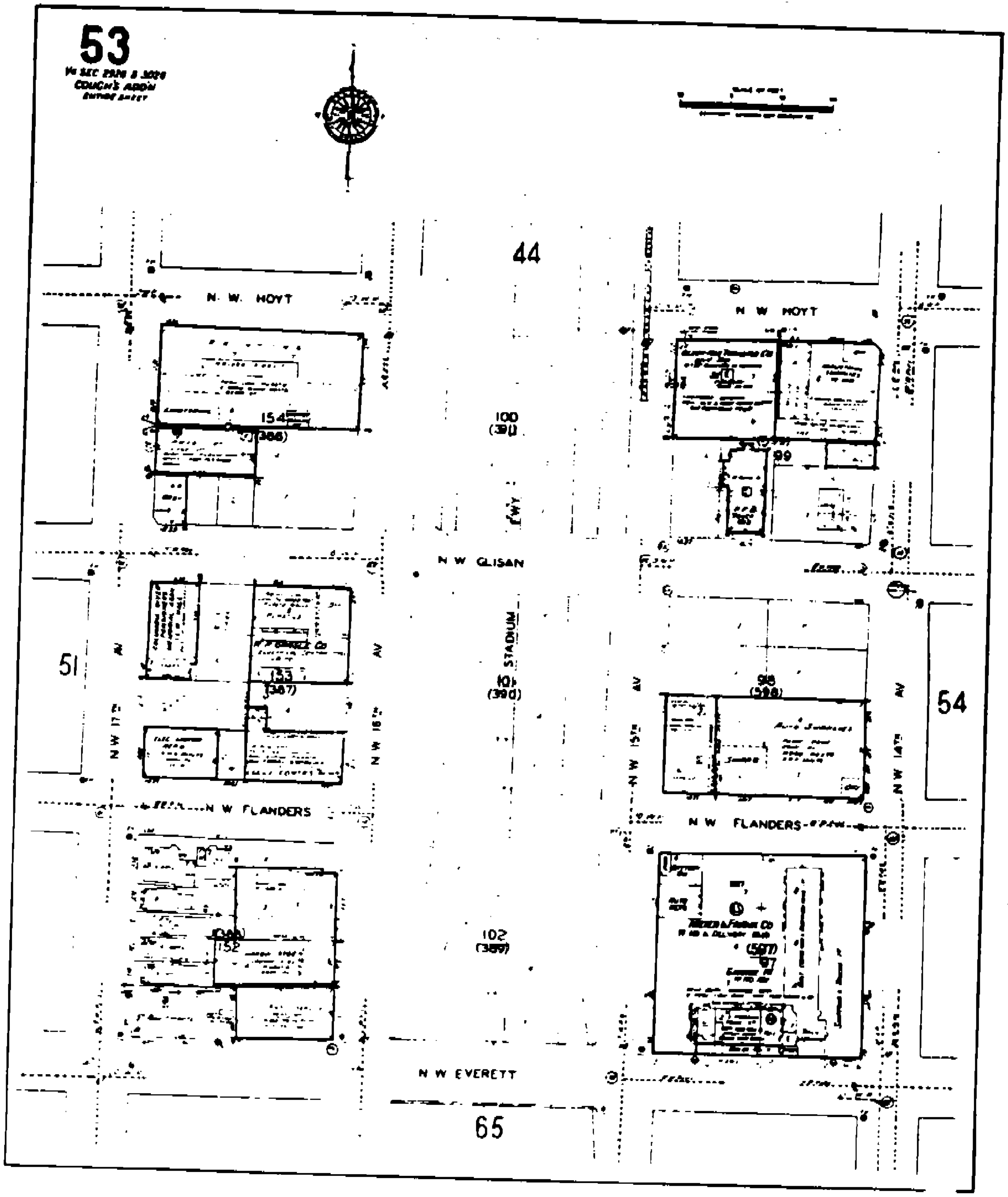
For more information, contact the ERTS Data Center, Sioux Falls, South Dakota, telephone: (605) 339-2270. The ERTS Data Center has substantial holdings of images acquired by aircraft throughout the United States. They invite inquiry regarding availability of suitable coverage of your area of interest (USGSEDC).

4. Sanborn Maps

Sanborn maps are land use maps prepared by the Sanborn Map Company. They are plotted to a scale of 1 in. to either 50 or 100 ft showing details such as streets, railroad tracks, lot lines, building dimensions, nature of the building material, number of stories, height of the building, and use of the building. Sanborn maps are used primarily for fire insurance purposes. Local sources may be fire insurance offices, realtors offices, city planning, and the county courthouse (Murphy, 1966). For information, contact:

The Sanborn Map company, Inc.
629 5th Avenue
Pelham, N. Y. 10803
Mr. G. Greeley Wells
Telephone: (914) 738-1649

Figure D-3 is an example of a Sanborn map for a section of Portland, Oregon.



SA-351.-23

FIGURE D-3 A SANBORN MAP FOR A SECTION OF PORTLAND, OREGON

Appendix E

BIBLIOGRAPHY

Appendix E

BIBLIOGRAPHY

A literature review has provided a collection of papers and reports on topics related to the measurement and distribution of CO concentrations. A number of foreign translations were provided by the Contract Monitor and are included in the bibliography. The bibliography is arranged alphabetically by author and numbered consecutively. Each item in the bibliography has been classified into the categories shown in Table 2 (see Section II of the text). The resulting matrix is given in Table E-1. The bibliography item number is entered in all the applicable categories. Some of the more comprehensive reports may be tallied in several categories. Table E-1 can be easily used to determine which of the reports in the bibliography are related to the various sampling purposes and scales of measurement.

Table E-1

BIBLIOGRAPHY INDEX, ARRANGED ACCORDING TO MEASUREMENT PURPOSES AND SCALES
(Numbers in Columns Refer to Numbers by Which Entries Are Cataloged in the Bibliography)

Purpose for Which Data Are to Be Used	Applicable Scale of Measurement				
	Middle			Neighborhood	Regional
	Downtown, Street Canyon	Indirect Source	Corridor		
1. Determine compliance with ambient air quality standards	36 41 57 69 72 111	43 57 69 72 111 136 138	28 57 58 69 70 71 138	1 28 43 57 69 70 71 81 82 96 136 138	28 29 30 36 58 69 70 71 81 96 124 136 138
2. Alert authorities to existing or impending critical situations	4 45 73 86 103 107 113	43 45 73 103 113	4 58 113	4 45 113	58 118
3. Evaluate results of control measures	36 98 113 126 131	98 113 126	58 62 113 126	102 117 126	36 58 117
4. Determine long-term trends, urban and rural			48	1 17 48 66 82 102 117	17 29 30 47 48 66 102 117 125
5. Provide information for developing, evaluating, and refining air pollution models	18 26 49 50 55 64 75 77 99 116	49 50 64 67 99	18 24 25 27 31 50 62 64 67 68 76 116 129	20 50 56 61 67 68 99 111 116 129	20 50 60 61 67 68 78 112 125
6. Provide information for comparisons among locations of the same general class, street canyons, highways, neighborhoods, rural areas	7 21 32 34 36 37 39 40 41 44 54 59 66 72 83 85 86 96 97 98 100 101 103 106 107 119 112 128 133 134 135	20 21 44 59 66 85 96 98 100 101 103 106 133 134	5 20 21 28 44 48 58 59 66 85 96 100 101 106	5 20 21 28 43 44 48 59 66 81 84 85 96 100 101 102 106 125	3 5 20 28 35 36 43 44 48 74 78 81 85 101 106 125
7. Serve as data base for city and regional planners and decision makers	96	67 96 105	28 33 58 62 67 96	2 16 17 19 28 33 43 63 66 67 79 80 96 105 114 117 120 123 132 137	2 16 17 19 28 29 30 33 58 66 67 79 80 106 114 117 120 123 125 132 137
8. Serve as a data base for environmental impact statements, highway projects, transportation plans, large developments, indirect sources		21 22 104 115	76	87 88 89 90 91 92 93 94 95	87 88 89 90 91 92 93 94 95
9. Provide measures of the magnitude of sources and sinks, anthropogenic, biological				51 52 53	51 52 53 108 109
10. Provide measures of indoor/outdoor concentration relationships	32 38 44 130	130			

BIBLIOGRAPHY

1 Akland, G. G., "Design of Sampling Schedules," JAPCA, Vol. 22, No. 4, April 1972, pp. 264-266

2 Alan M. Voorhees and Asso., Inc., and Ryckman, Edgerley, Tomlinson and Asso., "A Guide to Reducing Air Pollution Through Urban Planning," for the Env. Protection Agency, APTD-093, December 1971, 114 p.

3 Aschbacher, P. W., "Air Pollution Research Needs: Livestock Production Systems," JAPCA, Vol. 23, No. 4, April 1973, pp. 267-272.

4 Babcock, L. R. and N. L. Nagda, "Cost Effectiveness of Emission Control," JAPCA, Vol. 23, No. 3, March 1973, pp. 173-179.

5 Bank, Marvin and Douglas M. McEachern, "A Carbon Monoxide Profile of a Main Traffic Artery in Mexico City," presented at 63rd Annual Meeting of the APCA, St. Louis, Missouri, June 1970.

6 Bastress, E. Karl, "Nature and Control of Aircraft Engine Exhaust Emissions," presented at 62nd Annual Meeting of the APCA , June 1969, (APCA No. 69-190).

7 Bayley, E and A. Dockerty, "Traffic Pollution of Urban Environments," J. Royal Soc. Health, 92 (1) pp. 6-11, Jan-Feb 1972.

8 Beard, R. R. and G. A. Wertheim, "Behaviorial Impairment, Associated with Small Doses of CO," Am. J. Pub. H. 57, November 67, pp. 2012-2002.

9 Beaton, J. L., J. B. Skog, and E. C. Shirley, "Traffic Information Requirements for Estimates of Highway Impact on Air Quality," Materials & Research Department Air Quality Manual, Division of Highways, State of California, April 1972, 29 pp.

10 Beaton, J. L., J. B. Skog, and E. C. Shirley, "A Method for Analyzing and Reporting Highway Impact on Air Quality," Materials and Research Department Air Quality Manual, Division of Highways, State of California, July 1972, 30 pp.

11 Beaton, J. L., J. B. Skog, and A. J. Ranzieri, "Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality," Materials and Research Department Air Quality Manual, Division of Highways, State of California, September 1972, 58 pp.

12 Beaton, J. L., J. B. Skog, E. C. Shirley, and A. J. Ranzieri, "Meteorology and its Influence on the Dispersion of Pollutants from Highway Line Sources," Materials and Research Department Air Quality Manual, Division of Highways, State of California, April 1972, 159 pp.

13 Beaton, J. L., J. B. Skog, E. C. Shirley, and A. J. Ranzieri, "Mathematical Approach to Estimating Highway Impact on Air Quality," Materials and Research Department Air Quality Manual, Division of Highways, State of California, July 1972, 65 pp.

14 Beaton, J. L., J. B. Skog, E. C. Shirley, and A. J. Ranzieri, "Mathematical Approach to Estimating Highway Impact on Air Quality, Appendix," Materials and Research Department Air Quality Manual, Division of Highways, State of California, July 1972, 107 pp.

15 Beaton, J. L., J. B. Skog, E. C. Shirley, and A. J. Ranzieri, "Analysis of Ambient Air Quality for Highway Projects," Materials and Research Department of Air Quality Manual, Division of Highwats, State of California, July 1972, 105 pp.

16 Berry, B. J. L., et al, "Land Use, Urban Form and Environmental Quality," Dept. of Geography, U. of Chicago, for the Office of Res. and Development, Environmental Protection Agency, 1974, 442 pp.

17 Bisselle, C. A., S. H. Lubore, and R. P. Pikul, "National Environmental Indices: Air Quality and Outdoor Recreation," The Mitre Corp., McLean, Va., for the Council on Environmental Quality, Wash., D.C., 1972, 262

18 Chang, T. Y. and B. Weinstock, "Urban CO Concentrations and Vehicle Emissions," JAPCA, Vol. 23, No. 8, August 1973, pp. 691-696.

19 Cooper, A. G., "Carbon Monoxide, A Bibliography with Abstracts," PHS Pub. No. 1503, U.S. Dept. of HEW, 1966, 440 pp.

20 Copley, Charles M., Jr., Division of Air Pollution Control, City of St. Louis, Missouri and D. A. Pecsok, Air Pollution Control, St. Louis, Missouri, "St. Louis Regional Air Monitoring Network," 63rd Annual Meeting - APCA, St. Louis, Mo., June 14-18.

21 Corning Laboratories, Inc., "Procedure for Constructing a Sample Station Network," Corning Laboratories Inc. (formerly Doerfer Labs), Cedar Falls, Iowa.

22 Dabberdt, W. F., and R. C. Sandys, and P. A. Buder, "A Population Exposure Index for Assessment of Air Quality Impact," SRI Project 3364, Final Report, July 1974, 43 pp.

23 Dabberdt, W. F., R. C. Sandys, and P. A. Buder, "Assessment of the Air Quality Impact of Indirect Sources," SRI Project 2947, Final Report, March 1974, 97 pp.

24 Danard, M. B., "Numerical Modeling of Carbon Monoxide Concentrations Near Highways," J. Appl. Meteor., Vol. 11, No. 6, September 1972, pp. 947-957.

25 Danard, M. B., R. S. Koneru, and P. R. Slawson, "A Numerical Model for Carbon Monoxide Concentration Near a Highway," Proceedings of Symposium on Air Pollution, Turbulence and Diffusion, December 7-10, 1971, New Mexico State University, pp. 152-157.

26 Drivas, P. J. and F. H. Shair, "Probing the Air Flow within the Wake Downwind of a Building by Means of a Tracer Technique," Atm. Env., Vol. 8, pp. 1165-1175.

27 Drivas, P. J. and F. H. Shair, "Dispersion of an Instantaneous Cross-Wind Line Source of Tracer Released from an Urban Highway," Atm. Env., Vol. 8, pp. 475-485.

28 Elkus, B. E., and K. R. Wilson, "Air Basin Pollution Response Function: The Weekend Effect," Dept. of Chem., U.C. San Diego, La Jolla, CA. Submitted to Science.

29 Environmental Protection Agency, 1973: The National Air Quality Program: Air Quality and Emissions Trends, Annual Report, Vol, II, 350 pp.

30 Environmental Protection Agency, "Monitoring and Air Quality Trends Report, 1972," EPA-450/1-73-004, Monitoring and Data Analysis Division, Durham, N.C., December 1973, 218 pp.

31 Eschenroeder, A. Q., "An Approach for Modeling the Effects of Carbon Monoxide on the Urban Freeway User," Internal Memorandum, IMR-1259, General Research Corp., Santa Barbara, Calif., January 1970.

32 Evans, D. W., "Carbon Monoxide Levels (Letter to the Editor)," JAPCA, Vol. 23, No. 12, December 1973 .

33 Everett, M. D., "Roadside Air Pollution Hazards in Recreational Land Use Planning," J. Am. Inst. of Planners, Vol. 40, No. 2, March 1974, pp. 83-89.

34 Fara, G. M., A Pagano, and G. Ziglio, "Investigation of Pollution from Motorized Traffic in the City of Milan," Minerva Medica, Vol. 64, No. 5, EPA Translation TR-265-74, January 1973, pp. 254-271.

35 Flynn, Ne. E., and W. R. Crouse, "Carbon Monoxide Emissions in the Bay Area - 1963," Bay Area Air Pollution Control District, San Francisco, Calif.

36 Fresno Air Pollution Study, State of California, Dept. of Public Health, (July 1960).

37 Fukuoka, S. et al., "Results of a Round-the-Clock Investigation of Carbon Monoxide at Some Intersections and their Vicinities," Tokyoto Kogai Kenkyusho Nenpo, Vol, 3, pp. 47-56 (March 1972) EPA Translation TR-259-74.

38 General Electric Co., "Indoor-Outdoor CO Pollution Study, for the Env. Protection Agency, EPA-R4-73-020, December 1972 .

39 Georgli, H. W., "Determination of CO Emission Concentrations Allowing for Meteorological Factors," February 1972, pp. 32-36.

40 Georgii, H. W., E. Busch, and E. Weber, 1967: Investigation of the Temporal and Spatial Distribution of the Immission Concentration of Carbon Monoxide in Frankfurt/Main, Report No. 11 of the Institute for Meteorology and Geophysics of the University of Frankfurt/Main (Translation No. 0477, NAPCA).

41 Geronimi, J., and J. Duffaud, "Carbon Monoxide Operation," Laboratoire Central Prefecture dePolice, Office of the Secreatry General, Ref. 65.794 D/PA, April 1971 , EPA Translation TR-264-74.

42 Giever, P. M., "Significance of CO as an Air Pollutant," J. Occup. Med., Vol. 9, 1967, p. 265.

43 Gilmore, T. M., and T. R. Hanna, "Regional Monitoring of Ambient Air Carbon Monoxide in Fairbands, Alaska," JAPCA, Vol. 24, No. 11, November 1974, pp. 1077-1079.

44 Godin, G., G. Wright, and R. J. Shephard, "Urban Exposure to Carbon Monoxide," Arch. Environmental Health, Vol. 25, November 1972, pp. 305-313.

45 Goldsmith, J. R. and S. A. Landaw, "Carbon Monoxide and Human Health," Sciences, Vol. 162, 20 December 1968, pp. 1352-1359.

46 Haskell, E. H., "Land Use and the Environment: Public Policy Issues," Environment Reporter, Monograph 20, Vol. 5, No. 28, November 8, 1974, 32 pp.

47 Heck, W. W., O. C. Taylor, and H. E. Heggestad, "Air Pollution Research Needs: Herbaceous and Ornamental Plants and Agriculturally Generated Pollutants," JAPCA, Vol. 23, No. 4, April 1973, pp. 357-266.

48 Hindawi, I. J., "Air Pollution Injury to Vegetation," NAPCA Publications AP-71, 1970 .

49 Hoydysh, W. G. and H. H. Chiu, "An Experimental and Theoretical Investigation of the Dispersion of Carbon Monoxide in the Urban Complex, Urban Technology Conf., AIAA Paper No. 71-523, New York Coliseum, New York, N.Y., May 24-26, 1971.

50 Hunt, W. F., Jr., "The Precision Associated with the Sampling Frequency of Log-Normally Distributed Air Pollutant Measurements," JAPCA, Vol. 22, No. 9, September 1972, pp. 687-691.

51 Inman, Robert E., Royal B. Ingersoll, and Elaine A. Levy, "Soil: A Natural Sink for Carbon Monoxide," Reprinted from Science, 18 June 1971, Volume 172, pp. 1229-1231.

52 Inman, R. and R. Ingersoll, "Tiny Fungi Eat Gas," SRI Intercom, No. 212, September 28, 1973, pp. 1.

53 Inman, R. E. and R. B. Ingersoll, Note on the "Uptake of Carbon Monoxide by Soil Fungi," APCA J., Vol. 21, No. 10, October 1971, pp. 646-647.

54 Iwasaki, K., S. Fukuoka, and T. Ohira, "On the Results of Continuous Measurements of Automobile Exhaust Gas in the Vicinity of the Ushigome Yanagicho Intersection," Tokyoto Kogai Kenkysha Kempo, Vol. 2, 1971, pp. 62-67, EPA Translation TR-278-74.

55 Johnson, W. B., W. F. Dabberdt, F. L. Ludwig and R. J. Allen, 1971: Field Study for Initial Evaluation of an Urban Diffusion Model for Carbon Monoxide, Comprehensive Report of Coordinating Research Council and Environmental Protection Agency, Contract CAPA-3-68 (1-69), Stanford Research Institute, Menlo Park.

56 Kahn, H. D., "Distribution of Air Pollutants (Note on)," JAPCA, Vol. 23, No. 11, November 1973, pp. 973.

57 Kanagawa Prefectural Environmental Pollution Center and Kanagawa Prefectural Pharamacists' Association, "Survey on Carbon Monoxide Environmental Pollution Caused by Automotive Exhaust Gas," Kanagawaken Taikiosen Chosaken Kyu Hokoku, No. 14, February 1972, pp. 33-45, EPA Translation TR-282-74.

58 Kauper, Erwin K. and Charlotte J. Hopper, "The Utilization of Optimum Meteorological Conditions for the Reduction of Los Angeles Automotive Pollution," JAPCA Vol. 15, No. 5, May 1965, pp. 210-213.

59 Kinosian, J. R., and D. Simeroth, "The Distribution of CO and Ox Concentrations in Urban Areas," Calif. Air Resources Board, Div. of Technical Services, Oct 1973 .

60 Knox, J. B., "Numerical Modeling of the Transport Diffusion and Deposition of Pollutants for Regions and Extended Scales," JAPCA, Vol. 24, No. 7, July 1974, pp. 660-664.

61 Knox, J. B. and R. Lange, "Surface Air Pollutant Concentration Frequency Distributions: Implications for Urban Modeling," JAPCA, Vol. 24, No. 1, January 1974, pp. 48-53.

62 Kurtzweg, C. L. and J. A. Kurtzweg, "Forecasting Carbon Monoxide Emissions on an Urban Freeway: The Effect of Traffic Management Techniques," presented at: The 65th Annual Meeting of the Air Pollution Control Association, Miami Beach, Florida 18-22 June 1972 .

63 Kurtzweg, C. L. and J. A. Kurtzweg, "Urban Planning and Air Pollution Control: A Review of Selected Recent Research," Am. Inst. of Planners Vol. 39, No. 2, March 1973, pp. 82-92.

64 Kurtzweg, J. A. and D. W. Weig, "Determining Air Pollutant Emissions from Transportation Systems," presented at: The Applications of Computers to the Problems of an Urban Society, October 24, 1969, New York, N.Y., U.S. Dept. of Health, Education and Welfare, National Air Pollution Control Administration, Durham, North Carolina.

65 Kwok, H.C.W., W. E. Langlois, and R. A. Ellefsen, "Digital Simulation of the Global Transport of Carbon Monoxide," IBM J. Res. Develop., January 1971, pp. 3-9.

66 Lahmann, E., "CO Concentrations in the Urban Areas of Berlin (Streets, Tunnels, Residential Areas and Water Bodies)," Staub-Reinhalt. Luft, Vol. 32, No. 2, February 1972, pp. 36-40.

67 Lamb, R. G., "An Air Pollution Model at Los Angeles," A Master's Thesis No. 2749, Univ. of California, Los Angeles, Calif., 1968, 104 pp.

68 Lamb, R. G. and M. Neiburger, "An Interim Version of a Generalized Urban Air Pollution Model," Atm. Env., Vol. 5, 1971, pp. 239-264.

69 Larsen, R. I., "Relating Air Pollutant Effects to Concentration and Control," JAPCA, Vol. 20, No. 4, April 1970, pp. 214-225.

70 Larsen, R. I., "An Air Quality Data Analysis System for Interrelating Effects, Standards, and Needed Source Reductions," JAPCA, Vol. 23, No. 11, November 1973, pp. 933-940.

71 Larsen, R. I., "An Air Quality Data Analysis System for Interrelating Effects, Standards, and Needed Source Reductions, Part 2," JAPCA, Vol. 24, No. 6, June 1974, pp. 551-558.

72 Larsen, R. I. and H. W. Burke, "Ambient Carbon Monoxide Exposures," APCA Paper 69-167, Presented at Annual Meeting of the APCA, New York, N.Y., 22-26 June 1969 .

73 Lauther, P. J., B. T. Commins, and M. Henderson, "Carbon Monoxide in Town Air, An Interim Report," Ann. Occup. Hyg., Vol. 5, Pergamon Press Ltd. , 1962, pp. 241-248.

74 Lillie, R., "Air Pollutants Affecting the Performance of Domestic Animals, A Literature Review," USDA Ag. Res. Service, Agriculture Handbook No. 380, January 1972 .

75 Ludwig, F. L. and W. F. Dabberdt, 1972: Evaluation of the APRAC-1A Urban Diffusion Model for Carbon Monoxide. Final Report, Coordinating Research Council, EPAC Contract CAPA-3-68 (1-69), Stanford Research Institute, Menlo Park, California, 147 pp.

76 Ludwig, F. L., W. B. Johnson, and R. E. Inman, 1975: Air Quality Impact Study for a Proposed Highway Widening Near Ojai, Part 2: Projected Impact, Final Report, California Department of Transportation Contract J-7292, Stanford Research Institute, Menlo Park, California, 111 pp.

77 Ludwig, F. L., W. B. Johnson, A. E. Moon and R. L. Mancuso, 1970: A Practical Multipurpose Urban Diffusion Model for Carbon Monoxide, Final Report, Coordinating Research Council Contract CAPA 3-68(1-68, National Air Poll. Contr. Admin. Contract CPA 22-69-64, 184 pp.

78 Ludwig, F. L. and J. H. S. Kealoha, 1974: Present and Prospective San Francisco Bay Area Air Quality, Final Report for Wallace, McHarg, Roberts and Todd and the Metropolitan Transportation Commission, Stanford Research Institute, Menlo Park, California, 110 pp.

79 Mahoney, J. R., "Fundamentals of Air Pollution Analysis for the Planner," source unknown; typed manuscript. July 16, 1972, pp. 1-8.

80 Mason, D. V., G. Ozolins, and C. B. Morita, "Sources and Air Pollutant Emission Patterns in Major Metropolitan Areas," APCA #69-101, Annual Meeting APCA, New York, N.Y., 23-26 June 1969.

81 McGuire, T. and K. E. Noll, "Relationships Between Concentrations of Atmospheric Pollutants and Averaging Time," presented at the 11th Conference on Methods in Air Pollution and Industrial Hygiene Studies, April 1, 1970.

82 McKee, H. C., J. H. Margeson, and T. W. Stanley, "Collaborative Testing of Methods to Measure Air Pollutants," JAPCA, Vol. 23, No. 10, October 1973, pp. 870-875.

83 Mortstedt, S. E., K. E. Egeback, N. Walde, and K. Bjorkqvist, "Measuring of Carbon Monoxide Contents in the Air in City Traffic in Stockholm and Gothenburg, May-June 1966," Aktiebolaget Atomenergi, October 6, 1962, 22 pp., EPA Translation TR-266-74.

84 Munn, R. E. and I. M. Stewart, "The Use of Meteorological Towers in Urban Air Pollution Programs," JAPCA, Vol. 17, No. 2, February 1967, pp. 98-101.

85 Nader, J. S., "Developments in Sampling and Analysis Instrumentation for Stationary Sources," JAPCA, Vol. 23, No. 7, July 1973, pp. 587-591.

86 Nakano, K. and T. Odaira, "Considerations on CO Conc, in Crossroads Environs," Annual Report of the Tokyo Metropolitan Research Institute for Environmental Protection, 1971, pp. 10-20.

87 National Air Pollution Control Administration, 1968 : Report for Consultation on the Washington, D.C., National Capital Interstate Air Quality Control Region, U.S. Department of HEW.

88 National Air Pollution Control Administration, 1968 : Report for Consultation on the Metropolitan Los Angeles Air Quality Control Region, U.S. Department of HEW.

89 National Air Pollution Control Administration, 1968 : Report for Consultation on the Metropolitan Boston Intrastate Air Quality Control Region, U.S. Department of HEW.

90 National Air Pollution Control Administration, 1968 : Report for Consultation on the San Francisco Bay Area Quality Control Region, U.S. Department of HEW.

91 National Air Pollution Control Administration, 1969 : Report for Consultation on the Metropolitan Pittsburgh City Intrastate Air Quality Control Region, U.S. Department of HEW.

92 National Air Pollution Control Administration, 1969 : Report for Consultation on the Greater Metropolitan Cleveland Intrastate Air Quality Control Region, U.S. Department of HEW.

93 National Air Pollution Control Administration, 1969 : Report for Consultation on the Metropolitan Kansas City Intrastate Air Quality Control Region, U.S. Department of HEW.

94 National Air Pollution Control Administration, 1969 : Report for Consultation on the Metropolitan Baltimore Intrastate Air Quality Control Region, U.S. Department of HEW.

95 National Air Pollution Control Administration, 1969 : Report for Consultation on the Hartford-Springfield Interstate Air Quality Control Region (Connecticut-Massachusetts), U.S. Department of HEW.

96 National Air Pollution Control Administration, "Air Quality Criteria for CO," NAPCA Pub. No. AP-62, U.S. Dept. of HEW, March 1970, 184 pp.

97 Nogami, J., M. Izumikawa, and S. Nakagishi, "CO Pollution from Automobile Exhaust," J. Japan Soc. of Air Pollution, Vol. 5, No. 1, 1970, pp. 237, EPA Translation TR-260-74.

98 Ott, W. R., "Need for Adequate Monitoring Siting Criteria," Manuscript, 2 April 1974, 6 pp.

99 Ott, W. R., "Development of Criteria for Siting Air Monitoring Stations," (draft) to be presented at the 68th Annual Meeting of the APCA, Boston, Mass., June 1975.

100 Ott, W. R., and R. Eliassen, "A Survey Technique for Determining the Representativeness of Urban Air Monitoring Stations with Respect to Carbon Monoxide," JAPCA Vol. 23, No. 3, August 1973, pp. 685-690.

101 Ott, W. R. and D. Mage, "The Representativeness of Urban Air Monitoring Stations with Respect to CO," Proceedings of the Second Annual Environmental Engineering and Sciences Conf., Louisville, KY., April 1972, pp. 379-394.

102 Ott, W. R. and D. T. Mage, "Trend Assessment of Air Quality Over Large Physical Areas by Random Sampling," presented at the 4th Annual Environmental Engineering and Science Conference, Kentucky, March 1974, p. 19.

103 Ott, W. R. and D. T. Mage, "A Method for Simulating the True Human Exposure of Critical Population Groups to Air Pollutants," presented at Int. Symp.: Recent Advances in the Assessment of the Health Effects of Environmental Pollution, Paris, June 1974, 11 pp.

104 Patterson, R. M. and F. A. Record, 1974: Monitoring and Analysis of Carbon Monoxide and Traffic Characteristics at Oakbrook, EPA Pub. No. EPA-450/3-74-058, 458 pp.

105 Perkins, N. M., 1973: Do Air Monitoring Station Data Represent the Surrounding Community Exposure? Int. J. Biometeorology, 17, pp. 23-28.

106 Pooler, F., Jr., "Network Requirements for the St. Louis Regional Air Pollution Study," JAPCA, Vol. 24, No 3, March 1974, pp. 228-231.

107 Public Damage Countermeasures Branch, Automotive Public Damage Subcommittee, "A Survey of Environmental Pollution by Automotive Exhaust Gases, Report No. 1, Pollution by CO," PDCB, Construction Division, Nerima District, Tokyo, 1971, 51 pp.

108 Robbins, R. C., K. M. Borg, and E. Robinson, "Carbon Monoxide in the Atmosphere," JAPCA, Vol. 18, No. 2, February 1968, pp. 106-110.

109 Robinson, E. and R. C. Robbins, 1957: Sources, Abundance, and Fate of Gaseous Pollutants, Prep. for Amer. Petroleum Inst. Final Report, Project PR-6755, Stanford Research Institute, Menlo Park, Calif.

110 Robinson, E. and R. Robbins, "Atmospheric CO Concentrations on the Greenland Ice Cap," J. Geophys, Res. 74, pp. 1968-1973, 1969.

111 Rossin, A. D., and J. J. Roberts, "Episode Control Criteria and Strategy for Carbon Monoxide," JAPCA, Vol. 22, No. 4, April 1972, pp. 254-259.

112 Rubin, E. S., "The Influence of Annual Meteorological Variations on Regional Air Pollution Modeling: A Case Study of Allegheny County Pennsylvania," JAPCA, Vol. 24, No. 4, April 1974, pp. 349-356.

113 Rust Engineering Co., The, and Applied Science Division, Litton Industrie "A Proposal for a System Engineering Study of Metropolitan Air Pollution Control," JAPCA, Vol. 17, No. 2, February 1967, pp. 98-101

114 Rydell, C. P., and G. Schwarz, "Air Pollution and the Shape of Urban Areas," J. Am. Inst. of Planners, 1968, pp. 50-51.

115 Sandys, R. C., P. A. Buder and W. F. Dabberdt, 1975: ISMAP--A Traffic Emissions/Dispersion Mode for Mobile Polluting Sources, User's Manual, prepared for the California Business Properties, Inc., Hawthorne, California, Stanford Research Institute, Menlo Park, California, in preparation.

116 Sauter, G. D. and W. R. Ott, "A Computer Program for Projections of Vehicular Pollutant Emissions in Urban Areas," JAPCA, Vol. 24, No. 1 January 1974, pp. 54-59.

117 Savas, E. S., "Computers in Urban Air Pollution Control Systems," Socio-Economics Planning Sciences, Vol. 1, No. 2, December 1967, pp. 157-183.

118 Sawyer, R. F., "Reducing Jet Pollution Before it Becomes Serious," Astronautics and Aeronautics, April 1970, pp. 62-67.

119 Schnelle, K. R., Jr., F. G. Siegler, and P. A. Krenkel, "A Study of the Vertical Distribution of CO and Temperature Above an Urban Intersection," presented at the 66th Annual Meeting of the APCA, Paper No. 69-152, June 1969.

120 Schulze. R. H., "The Economics of Environmental Quality Measurement," JAPCA, Vol. 23, No. 8, August 1973, pp. 671-675.

121 Seiler, W. and C. Junge, "Carbon Monoxide in the Atmosphere," Max Planck Institute for Chemistry (Otto Hahn Institute) Mainz, Germany. Source unclear; sometime after 1969.

122 Seki, T., H. Hoshikawa, M. Suzuki and T. Sugano, "Air Pollution at the Street Level Due to Automobile Exhaust in Sendai City," (Report No. 5), EPA Translation TR-283-74, Sendaishi Eisei Ken Kyshoho, pp. 210-216.

123 Senate Document No. 92, "Progress in the Prevention and Control of Air Pollution," 90th Congress, 28 June 1968, p. 85.

124 South Coast Air Basin Coordinating Council, "Air Monitoring Site Criteria," Air Monitoring Subcommittee, Tec. Advisory Committee, 10 pp.

125 Stanford Research Institute, 1972: Regional Air Pollution Study: A Prospectus, Part III-Research Facility, Final Report EPA Contract 68-02-0207. Stanford Research Institute, Menlo Park, California, 167 pp.

126 Stanley, W. J., "Air Resource Management in the City of Chicago, Pollution Incident Control Plan," APCA, No. 68-56, presented at 61st Annual Meeting of APCA, St. Paul, Minn., 27 June 1968 .

127 Stern, A. C., "Strengthening the Clean Air Act," JAPCA, Vol. 23, No. 12, December 1973, pp. 1019-1022.

128 Stuart, D. G., "Planning for Pedestrians," J. Am. Inst. of Planners, 1968, pp. 37-41.

129 Sweet, A. H., B. J. Steigerwald, and J. H. Ludwig, "The Need for a Pollution-Free Vehicle," National Center for Air Pollution Control, JAPCA, Vol. 18, No. 2, February 1968.

130 Thompson, C. R., E. G. Hensel and G. Kats, "Outdoor-Indoor Levels of Six Air Pollutants," JAPCA, Vol. 23, No. 10, October 1973, pp. 881-886.

131 Tokyo Metropolitan Government, Environmental Pollution Dept., Regulation Section, "Results of Environmental Survey of the Vicinity of the Itsukaichi Kaidoguchi Intersection in Suginami Ward, May 1973," EPA Translation TR-280-74.

132 Tromp and Sargent (Editors), "A Survey of Human Biometeorology," Tec. Note No. 65, WMO-No. 160.TP.78, Geneva, Switzerland 1964, 109 pp.

133 Ukai, H., K. Uno, Y. Ose, K. Sasaki, and M. Kiriyama, "Study of Automobile Exhaust in Gifu City," J. Japan Society of Air Pollution, Vol. 5, No. 1, 1970, pp. 245, EPA Translation TR-261-74.

134 Umezawa, M., K. Umehara, T. Asaoka, and M. Endo, "Results of a Survey of Air Pollution Caused by Automobile Exhaust in Shizuok Prefecture, Environmental Pollution Control and Research Center of Shizuoka Prefecture, 3 p., EPA Translation TR-279-74.

135 Wada, A., E. Ito, M. Hayakawa, M. Kitase, and H. Mizutani, "Automotive Exhaust Gas Pollution of Main Throughfares in Nagoya," Taiki Osen Kankyu, Vol. 6, No. 1, 1971, p. 231, EPA Translation TR-263-74.

136 Walther, E. G., "A Rating of the Major Air Pollutants and Their Sources by Effect," JAPCA, Vol. 25, No. 5, May 1972, pp. 352-355.

137 Willis, B. H. and J. R. Mahoney, "Planning for Air Quality," (Typed Manuscript -- paper presented at Confer-In 1972), Environmental Research and Technology, Inc., Mass. 16 pp.

138 Wilting, J. J. and H. Van den Berge, "Air Pollution Monitoring Network in the Netherlands," Computer, July/August, 1971, pp. 23-27.

139 Yanagisawa, S., "Air Quality Standards, National and International," JAPCA, Vol. 23, No. 11, November 1973, pp. 945-948.

REFERENCES

Beaton, J. L. et al., 1972a: "Meteorology and its Influence on the Dispersion of Pollutants from Highway Line Sources," California Division of Highways, 158 pp.

Beaton, J. L. et al, 1972b: "Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality," California Division of Highways, 58 pp.

Beaton, J. L. et al., 1972c: "Traffic Information Requirements for Estimates of Highway Impact on Air Quality," California Division ofHighways, 29 pp.

Beaton, J. L. et al., 1972d: Mathematical Approach to Estimating Highway Impact on Air Quality," California Division of Highways, 65 pp.

Beaton, J. L. et al., 1972e: "Mathematical Approach to Estimating Highway Impact on Air Quality, Appendix," California Division of Highways, 107 pp.

Beaton, J. L. et al., 1972f: "Analysis of Ambient Air Quality for Highway Evvironmental Projects," California Division of Highways, 105 pp.

Beaton, J. L. et al., 1972g: "A Method for Analyzing and Reporting Highway Impact on Air Quality," California Divison of Highways, 30 pp.

Busse A. D. and J. R. Zimmerman, 1973: "User's Guide for the Climatological Dispersion Model," Environmental Protection Agency Report No. EPA-R4-73-024, 131 pp.

California Division of Highways, 1971: "Traffic Volumes on the California State Highway System," 188 pp.

Cavender, J. H., D. S. Kircher, and A. J. Hoffman, 1973: Nationwide Air Pollutant Emission Trends, 1940-1970, U.S. Environmental Protection Agency Publication No. AP-115, 52 pp.

Dabberdt, W. F., 1975: "Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flows and Air Quality on and Near Highways," Quarterly Progress Report 5 and Monthly Progress Report, Federal Highway Administration Office of Research Contract DOT-FH-11-8125, Stanford Research Institute, Menlo Park, California, 13 February 1975, 32 pp.

Dabberdt, W. F., and P. A. Davis, 1974: "Determination of Energetic Characteristics of Urban-Rural Surfaces in the Greater St. Louis Area," Environmental Protection Agency Contract 68-02-1015, Stanford Reseach Institute, Menlo Park, California, April 1974, 101 pp.

Environmental Protection Agency, 1973:" The National Air Quality Program: Air Quality and Emissions Trends," Annual Report, Vol. II, 350 pp.

Georgii, H. W., E. Busch, and E. Weber, 1967: "Investigation of the Temporal and Spatial Distribution of the Immission Concentration of Carbon Monoxide in Frankfurt/Main," Report No. 11 of the Institute for Meteorology and Geophysics of the University of Frankfurt/Main (Translation No. 0477, NAPCA).

Gifford, F. A., Jr., 1961: Use of routine meteorological observations for estimating atmospherica dispersion, Nuclear Safety, 2, 48.

Johnson, W. B. et al., 1971: "Field Study for Initial Evaluation of an Urban Diffusion Model for Carbon Monoxide, Comprehensive Report of Coordinating Research Council and Environmental Protection Agency, Contract CAPA-3-68 (1-69), Stanford Research Institute, Menlo Park, California, 240 pp., National Technical Information Service No. PB 203469.

Kinosian, J. R. and D. Simeroth, 1973: "The Distribution of Carbon Monoxide and Oxidant Concentrations in Urban Areas," California Air Resources Board, 19 pp.

Ludwig, F. L. and W. F. Dabberdt, 1972: "Evaluation of the APRAC-1A Urban Diffusion Model for Carbon Monoxide," Final Report, Coordinating Research Council, EPAC Contract CAPA-3-68 (1-69), Stanford Research Institute, Menlo Park, California, 147 pp.

Ludwig, F. L., W. B. Johnson, and R. E. Inman, 1975: "Air Quality Impact Study for a Proposed Highway Widening Near Ojai, Part 2: Projected Impact," Final Report, California Department of Transportation Contract J-7290, Stanford Research Institute, Menlo Park, California, in preparation.

Ludwig, F. L. and W. F. Dabberdt, 1973: "Effects of Urbanization on Turbulent Diffusion and Mixing Depth," Int. J. Biometeorol., Vol. 17, p. 1.

Ludwig, F. L., W. B. Johnson, A. E. Moon and R. L. Mancuso, 1970: A Practical Multipurpose Urban Diffusion Model for Carbon Monoxide," Final Report, Coordinating Research Council Contract CAPA 3-68(1-68), National Air Poll. Contr. Admin. Contract CPA 22-69-64, 184 pp.

Ludwig, F. L. and J.H.S. Kealoha, 1974: "Present and Prospective San Francisco Bay Area Air Quality," Final Report for Wallace, McHarg, Roberts and Todd and the Metropolitan Transportation Commission, Stanford Research Institute, Menlo Park, California, 110 pp.

McElroy, J. L., and F. Pooler, Jr., 1968: "St. Louis Dispersion Study, Vol. II--Analysis," National Air Pollution Control Administration Publication No. AP-53, 51pp.

Murphy, E., 1966: The American City: An Urban Geography, McGraw-Hill Book Co, p. 464.

National Oceanographic and Atmospheric Administation, 1968: "The Climatic Atlas of the United States," 80 pp.

Ott, W. 1971: "An urban Survey Technique for Measuring the Spatial Variation of Carbon Monoxide Concentrations in Cities," PhD thesis, Department of Civil Engineering, Stanford University, Stanford, California, 153 pp.

Ott, W., 1975: "Development of Criteria for Siting Air Monitoring Stations, Presented at the 68th Annual Meeting of Air Pollution Control Association," Boston, Mass., June, 1975.

Ott, W., J. F. Clarke, and G. Ozolins, 1967: "Calculating Future Carbon Monoxide Emissions and Concentrations from Urban Traffic Data, PHS Publ. No. 999-AP-41," National Center for Air Pollution Control, Cincinnati, Ohio.

Ott, W. and D. Mage, 1974: "Trend Assessment of Air Quality Over Large Physical Areas by Random Sampling," paper presented at the Fourth Annual Environmental Engineering and Science Conference, Louisville, Kentucky, March 5, 1974.

Pasquill, F., 1961:" The Estimation of the Dispersion of Windborne Material", Meteorological Mag. (London), Vol. 90, pp. 33-49.

Patterson, R. M. and F. A. Record, 1974: "Monitoring and Analysis of carbon monoxide and traffic Characteristics at Oakbrook," EPA Pub. No. EPA-450/3-74-058, 458 pp.

Perkins, N. M., 1973: "Do Air Monitoring Station data Represent the Surrounding Community Exposure?," Int. J. Biometeorology, 17, 23-28.

Roberts, P. J. W., P. M. Roth and C. L. Nelson, 1971: "Contaminant Emissions in the Los Angeles Basin—Their Sources, Rates and Distributions," Report EPA Contract CPA 70-168. Systems Applications, Inc., Beverly Hills, California, 85 pp.

Robinson, E. and R. C. Robbins, 1967: "Sources, Abundance, and Fate of Gaseous Pollutants", prepared for Amer. Petroleum Inst. Final Report, Project PR-6755, Stanford Research Institute, Menlo Park, Calif.

Sandys, R. C., P. A. Buder and W. F. Dabberdt, 1975: "ISMAP—A Traffic Emissions/Dispersion Model for Mobile Polluting Sources, User's Manual," prepared for the California Business Properties, Inc., Hawthorne, California. Stanford Research Institute, Menlo Park, California, in preparation.

Slade, D. H. (ed.), 1968: "Meteorology and Atomic Energy," U.S. Atomic Energy Commission, Oak Ridge, Tenessee, 445 pp.

Stanford Research Institute, 1972: "Regional Air Pollution Study: A Prospectus, Part III-Research Facility," Final Report EPA Contract 68-02-0207. Stanford Research Institute, Menlo Park, California, 167 pp.

REFERENCES (Concluded)

Stanford University Aerosol Laboratory and the Ralph M. Parsons Co., 1953a: "Behavior of Aerosol Clouds Within Cities," Joint Quarterly Report No. 3, January-March 1952, Contracts DA-18-064-CML-1856 and DA-18-064-CML-2282, DDC No. AD31711, Stanford University Aerosol Laboratory and the Ralph M. Parsons Co., 1953b: ibid; Joint Quarterly Report No. 4, April-June 1953, DDC No. AD31508.

Stanford University Aerosol Laboratory and The Ralph M. Parsons Co., 1953c: ibid; Joint Quarterly Report No. 5, July-Sept., 1953, 238 pp., DDC No. AD31507.

Stanford University Aerosol Laboratory and The Ralph M. Parsons Co., 1593d: ibid; Joint Quarterly Report No. 6, Vol. I, October-December, 1953, DDC No. AD31510.

Stanford University Aerosol Laboratory and The Ralph M. Parsons Co., 1953e: ibid; Joint Quarterly Report No. 6, Vol. II, October-December 1953, DDC No. AD31711.

Turner, D. B., 1969: "Workbook of Atmospheric Dispersion Estimates National Air Pollution Control Administration," 84 pp.

United States Geological Survey, 1969: "Topographic Maps," 22 pp., (April 1969).

United States Geological Survey, 1974; "Orthophotoquad Index," (chart) (December 1974).

United States Geological Survey, EROS Data Center, 1972: "Ordering ERTS Images from the EROS Data Center," EDCDM Form 6, 1 p. (4 August 1972).

United States Geological Survey, EROS Data Center, 1974: Pamphlet INF-74-22 (R.1).

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-75-077	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Selecting Sites for Carbon Monoxide Monitoring		5. REPORT DATE September 1975
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) F. L. Ludwig and J.H.S. Kealoha		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Stanford Research Institute Menlo Park, California 94025		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-1471
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency Office of Air and Waste Management Office of Air Quality Planning & Standards Research Triangle Park, N.C. 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report presents procedures and criteria for selecting appropriate locations for carbon monoxide (CO) monitoring stations. The purposes for which CO concentrations are measured are reviewed and classified according to a system based on special scales of representativeness.

Procedures are given for selecting locations that will provide CO measurements representative of downtown street canyon areas, along major traffic corridors, urban neighborhoods, and larger interurban regions. Specific recommendations are included for inlet heights, distances from major and minor roadways and placement relative to urban areas.

The rationale behind the specific recommendations is given.

Appendices discuss sources of information useful to the site selection process, such as climatological data, land use information, and traffic data. A bibliography is also included. It is classified according to monitoring purposes and scales of representativeness. A computer program designed to identify "worst-case" conditions and the relative contributions of sources at different distances is presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
carbon monoxide site exposure criteria site selection monitoring objectives air pollution		

18. DISTRIBUTION STATEMENT unlimited	19. SECURITY CLASS (This Report) unclassified	21. NO. OF PAGES 172
	20. SECURITY CLASS (This page) unclassified	22. PRICE

EPA Form 2220-1 (9-73)